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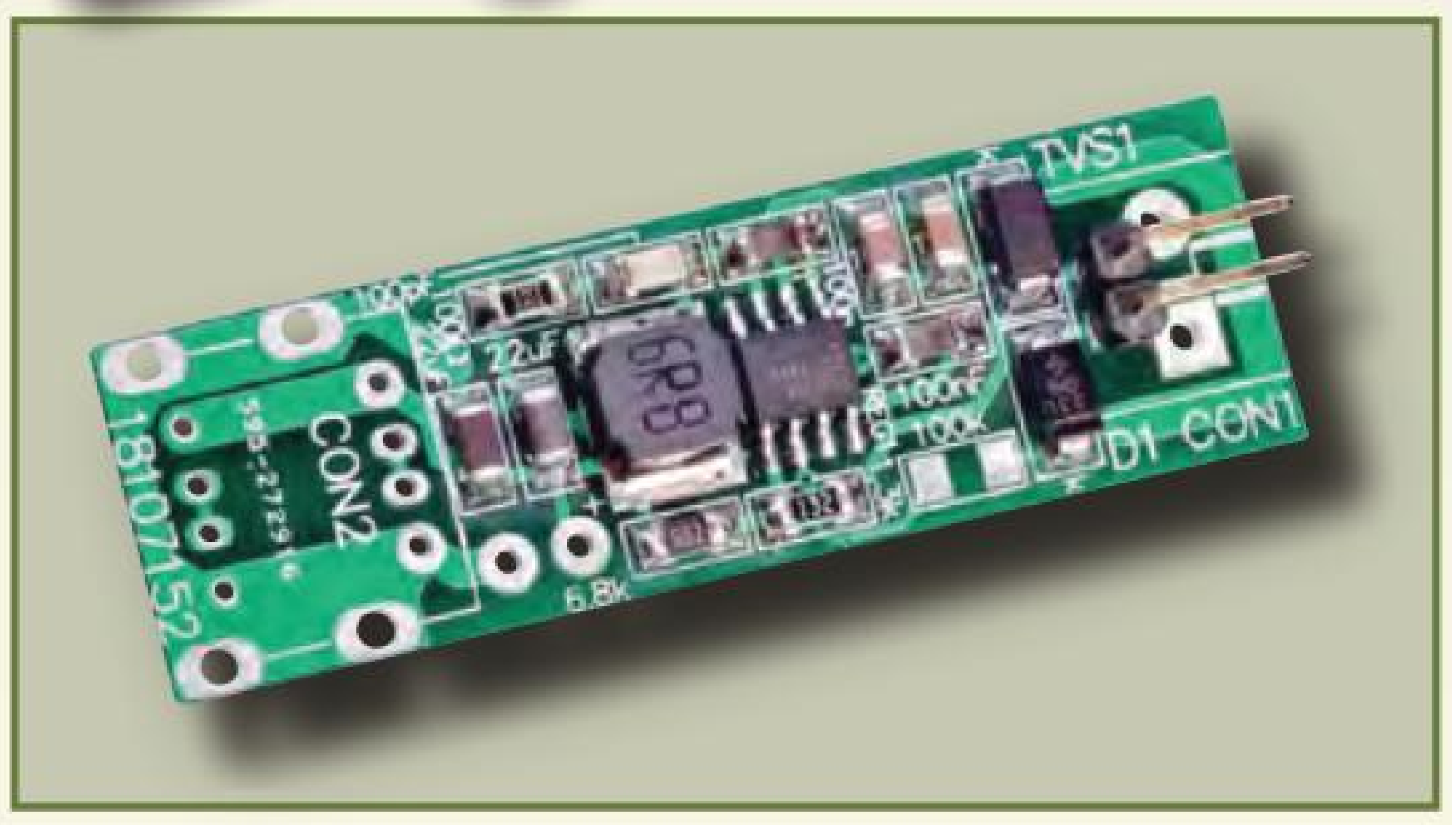

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Projects and Circuits

UNIVERSAL LOUDSPEAKER PROTECTOR 12
by Nicholas Vinen
Safeguard your expensive loudspeakers from catastrophic faults in amplifiers

9-CHANNEL INFRARED REMOTE CONTROL 24
by John Clarke
Control up to three separate receivers, each with seven channels

REVISED USB CHARGER REGULATOR WITH LOW BATTERY CUT-OUT 36
by Nicholas Vinen
Build this upgraded compact charger with battery protection and extra current capability

Series and Features

TECHNO TALK by Mark Nelson 11
The high price of cleanliness

TEACH-IN 2016 – EXPLORING THE ARDUINO 40
by Mike and Richard Tooley
Part 11: Global Positioning System

NET WORK by Alan Winstanley 49
In the Echo chamber... Dashed to pieces

CIRCUIT SURGERY by Ian Bell 50
Op amp instability – Part 2

PIC n' MIX by Mike O'Keeffe 54
PICs and the PICkit 3: A beginner's guide – Part 7

AUDIO OUT by Jake Rothman 58
Totally derailed: powering amplifiers – Part 1

MAX'S HOT BEANS by Max The Magnificent 66
High-end VR… Crème de la crème... Rift vs Vive... And what of the future?

ELECTRONIC BUILDING BLOCKS by Julian Edgar 68
Good Quality 2.1 Amplifier Module

Regulars and Services

SUBSCRIBE TO *EPE* and save money 4

***EPE* AND MICROCHIP SPECIAL OFFER** 5

EDITORIAL 7
Farewell 2016, hello 2017!... Looking for Christmas inspiration?

NEWS – Barry Fox highlights technology's leading edge 8
Plus everyday news from the world of electronics

***EPE* BACK ISSUES CD-ROM** 22

MICROCHIP READER OFFER 23
EPE Exclusive – Win a Microchip Explorer 16/32 Development Kit

***EPE* PCB & CDROM SALE!** 61

***EPE* CD ROMS FOR ELECTRONICS** 62
A wide range of technical books available by mail order, plus more CD-ROMs

***EPE* PCB SERVICE** 70
PCBs for *EPE* projects

ADVERTISERS INDEX 71

NEXT MONTH! – Highlights of next month's *EPE* 72

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Our January 2017 issue will be published on Thursday 1 December 2016, see page 72 for details.

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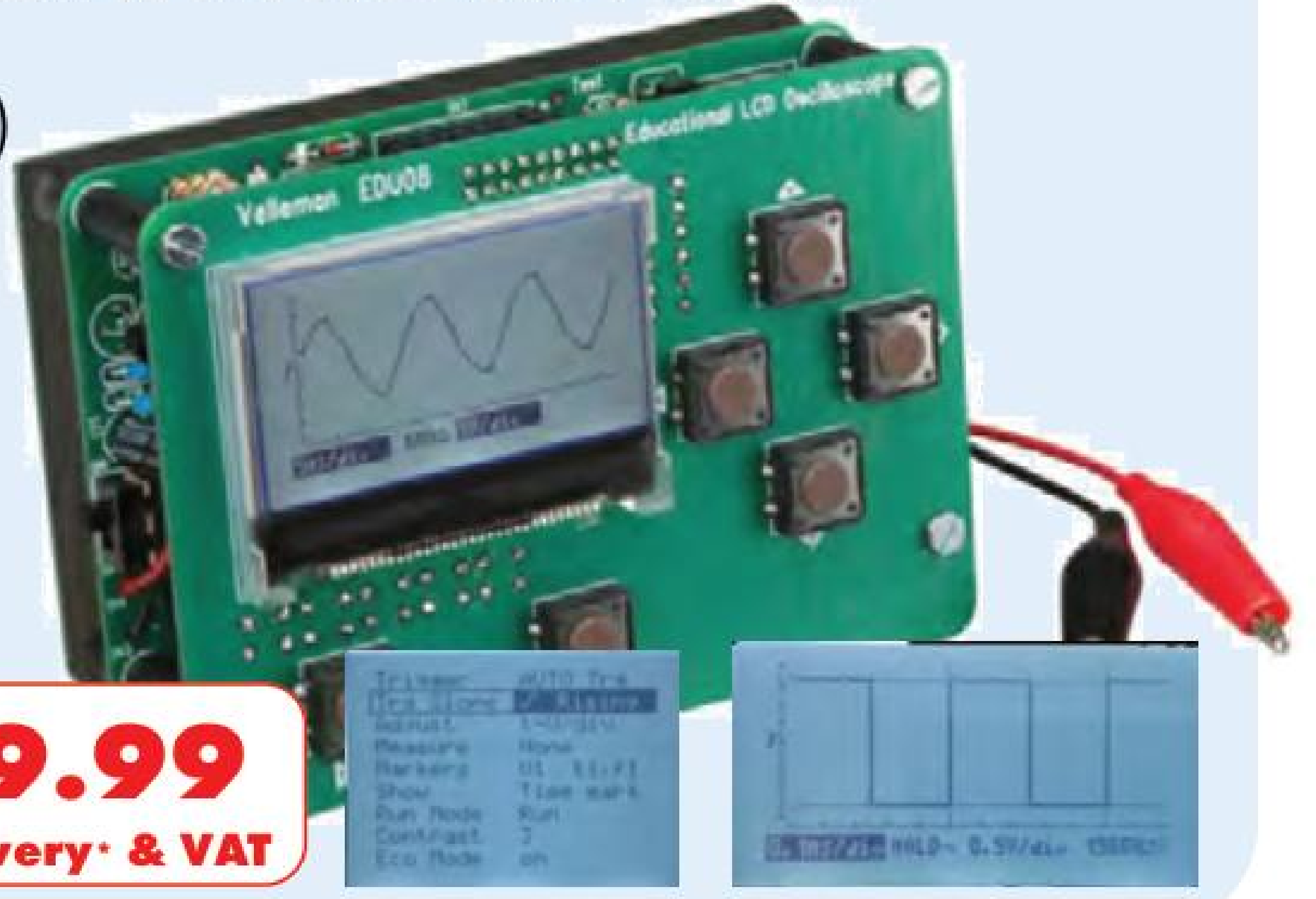

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EPE EVERYDAY PRACTICAL ELECTRONICS

Farewell 2016, hello 2017!

And here we are again – the final issue of the year – welcome to December 2016! It's been a great year for us at *EPE* and I hope you have enjoyed your year of designing, soldering and perhaps even troubleshooting with the latest copy of *EPE* beside you on your bench. We've had 12 great issues and it's only right that I salute our regular contributors for their steadfast support, imagination and strict adherence to deadlines… mostly!

In absolutely no particular order, a huge 'thank you' to Alan Winstanley, Mike and Richard Tooley, Ian Bell, Mark Nelson, Mike O'Keeffe, Clive 'Max' Maxfield, Robert Penfold, Julian Edgar and Jake Rothman. I know just how difficult it is to come up with new ideas and new material month in month out, and I really do appreciate all your very hard work.

So, what do we have planned for our loyal readership in 2017? The Tooley's are currently earning a well-earned rest after 12 months of unrelenting Arduino effort, but there will definitely be a *Teach-In 2017* and I'm sure it will be special. Looking ahead to our project list, there is something for everyone. From multi-issue Hi-Fi projects, to quick-and-easy Raspberry Pi circuits, there's a design to match every level of ability and depth of wallet. We have projects involving solar cells, GPS, alarms, instrumentation, bench equipment and much more. 2017 will be a great year for *EPE* and its readers!

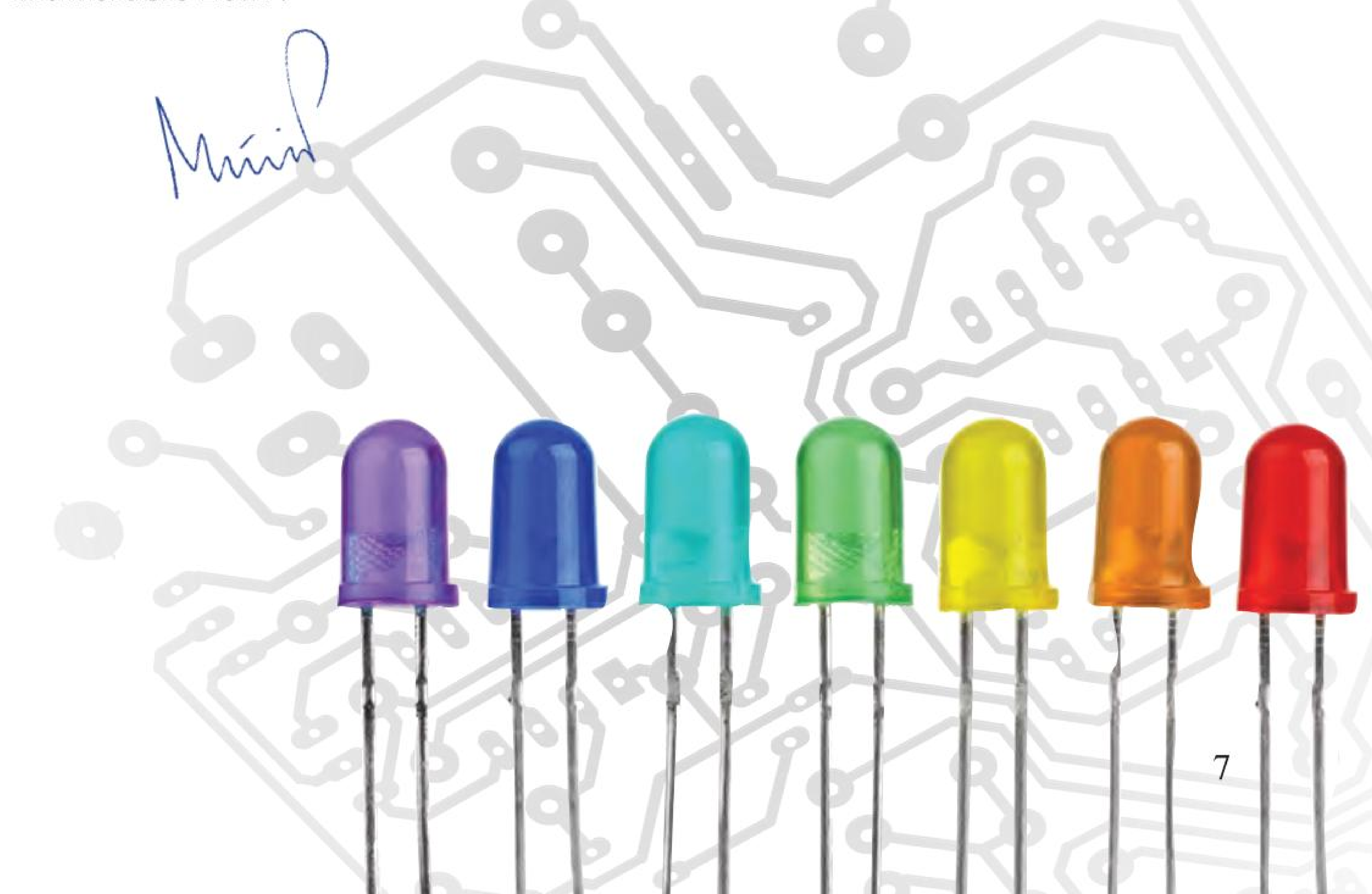
Looking for Christmas inspiration?

If you are lost for ideas when the tricky 'What would you like for Christmas?' question comes your way, then why not suggest a subscription to your favourite magazine – it doesn't matter whether you choose paper or online, as a subscriber you can be sure that you won't miss out...

One last thing

…and now, in the famous words of Steve Jobs, 'there is one more thing'! If you are in the market for subscription renewal this month then do turn to page 5 of this issue. We have a very special offer courtesy of our good friends at Microchip. Spend £125 on any *EPE* product – including subscriptions – and we will give you a PICkit 3 with a 44-pin Demo Board – *for FREE!* This really is a superb offer and a fantastic way to get into PIC design. We have 50 kits to give away and it's first come, first served – so don't delay.

From all of us at *EPE*, thank you for you support during 2016, and have a memorable 2017!



NEWS

A roundup of the latest Everyday News from the world of electronics

Screen tech update from Berlin IFA – report *by Barry Fox*

Another September, another IFA consumer electronics show in Berlin. Just like last year, the main focus was on 4K TV with 'more pixels', but this year also 'better pixels' thanks to HDR (high dynamic range) instead of SDR (standard dynamic range).

Battle of the dynamic range standards

The HDR10 system, used for Blu-ray and in many HDR TV sets, needs only minimal metadata to optimise picture contrast for whatever TV screen is being used, (compared to around 20% overhead for Dolby Vision). But the fact that HDR10 still needs some metadata makes it less suitable for live broadcasts – eg, when the camera pans from the dark to sunlit ends of a soccer pitch. HDR10 is best for pre-mastered content like movies.

Says Danny Tack, the design brains behind Philips/TP Vision sets: 'With regard to Dolby Vision, I ask myself, "Why would I want to use it?" I can see no reason. All HDR content is available with HDR10. So if we don't offer DolbyVision, no-one is missing anything.'

The BBC/NHK HLG, Hybrid Log Gamma system is winning support because it needs no metadata at all. Instead, HLG relies on a 'look-up' table embedded in the receiver to combine the old gamma system for conversion of electric signal to light, dating back to the days of CRTs, with modern logarithmic conversion, and so extends dynamic range from SDR to HDR. Also, HLG is backwards compatible with existing modern sets.

The only thing now holding HLG back is the lack of a standard for sending the signals over an HDMI cable; but this is expected soon.

Philips back OLED screen technology

There were also more OLED screens to be seen at IFA this year, because they can now run brighter, and panel-supplier LG has been making price offers other manufacturers cannot refuse. Philips/TP Vision has moved from an anti-OLED stance, through 'maybe OLED next year', to full-blown OLED enthusiasm.

Says Danny Tack: 'OLED is in many ways perfect – perfect on colour, perfect on contrast, perfect on motion and perfect on viewing angle. OLED can go down to 0 nits, with no halos. If you say LED displays give 100% colour gamut, then OLED gives 114%, even at low light levels. Switching is faster, which means sharper motion. The viewing angle is wider than for LED. The one weak spot is brightness, with OLED peaks at 500-700 nits but full white screen display at 150 nits.'

Only Samsung is still saying no to OLED, with a big push at IFA on quantum dot screens with the promise of a 10 year guarantee and sly digs at LG and OLED's unproven life and stability.

Japanese cooperation

Panasonic's take on OLED caught interest because the company says it is combining 'decades of plasma picture quality knowledge with native 4K UHD resolution and OLED screen technology'.

Demonstrations of a prototype 4K OLED impressed, but Panasonic would give no information on what new tricks it may be playing with LG's OLED panels, saying only that 'more information is expected to be announced later this winter'.

Patents filed by Panasonic over the last decade reveal that Panasonic Liquid Crystal Display Co Ltd has been co-operating with Hitachi Displays Ltd on OLED TV technology – probably after the Japanese Government urged rival companies to co-operate so as to better compete with Korea.

Matsushita's patents (US 2009/0046087 and 2009/0212715) teach how to dim OLEDs, smoothly and without flicker, by driving them with a pulsed voltage, and varying the shape and frequency of the pulse train. US filing 2009/0153449 describes advances in OLED screen technology and related Japanese patents (JP 12359455 and JP 20120014182) name Hitachi and Panasonic as joint applicants.

Together, these patents explain how using thin-film transistors (TFT) to switch OLED pixels improves light output and makes the screen look brighter, but blurs motion. This works because residual picture signals linger in the TFT capacitors so that one picture scan smears into the next.

The patented solution is to completely quench all the pixels between every scanning line, rather like physically switching off a light. The extreme quenching is done by rapidly reversing the voltage after each line scan.

The result, say the patents, is prevention of the blurred edge 'phenomenon', which 'greatly improves' motion clarity.

Windows 7 or 10?

And finally… in light of a recent *Which?* report, which heavily criticises Windows 10, it was interesting to see that the Press Room at IFA was providing banks of Fujitsu PCs, all with Windows 7 Pro. The support desk said: 'Supporting Windows 10 machines would be too difficult'.

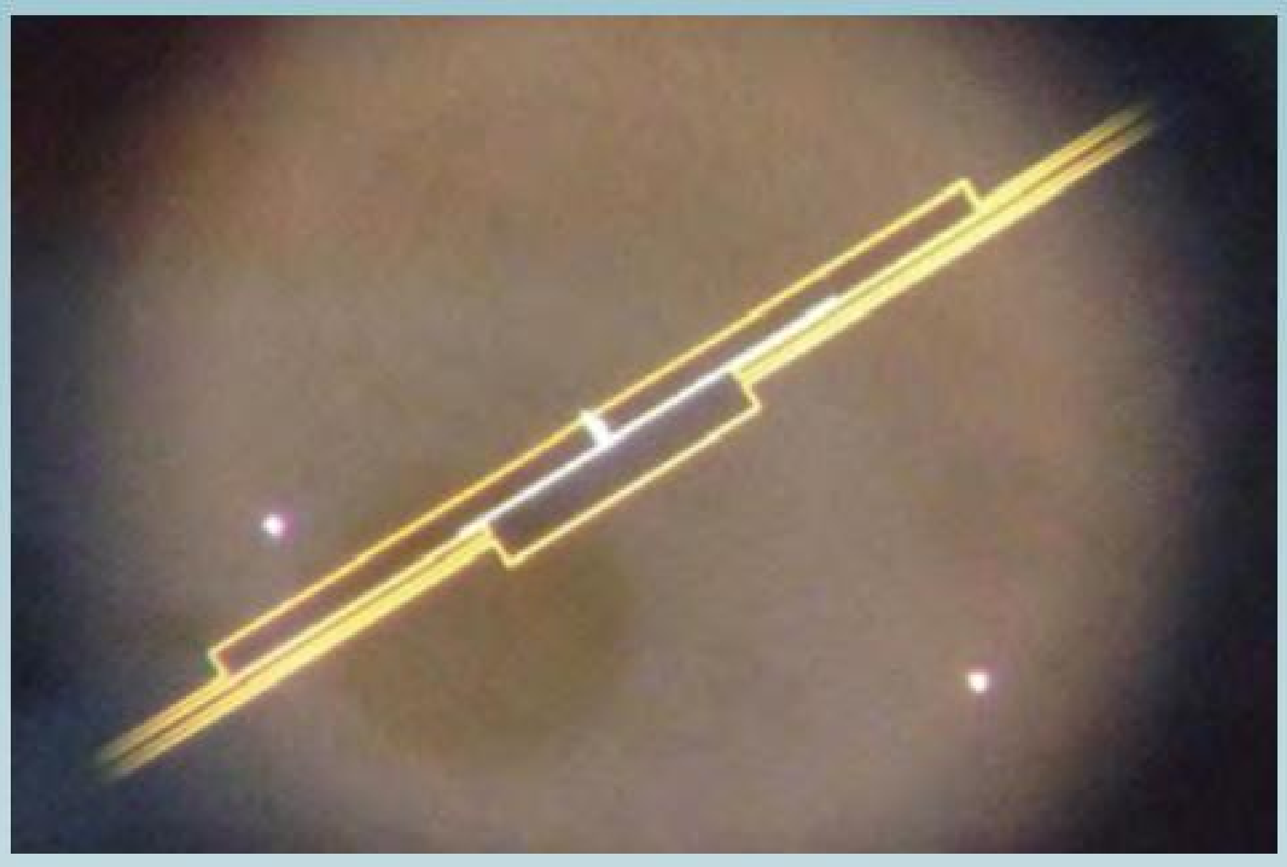
Single-photon microwaves

An international consortium of researchers has developed a tuneable, high-efficiency, single-photon microwave source, which has great potential for applications in quantum computing.

Circuits that produce single photons are a vital component in quantum computers. They usually consist of a quantum bit or 'qubit', coupled to a resonant circuit. The resonant circuit limits the photon output to specific frequencies depending on the design of the circuit. This limitation means that researchers have to rebuild them each time a different frequency is required, which is time and labour intensive.

A team of researchers at Royal Holloway, University of London and the National Physical Laboratory, together with colleagues from Moscow and Japan has solved this problem by creating a new device which is tuneable and is able to produce single photons over a wide range of frequencies on demand.

The technology uses a super-cooled qubit that bridges two open ends of a broken transmission line. One end, through which microwave photons are outputted, is strongly coupled to the qubit. The other end of the transmission line is weakly coupled and is used as the input port to trigger the emission of a single photon from the qubit. An input pulse is used to excite the qubit into a higher energy-state similar to an electron orbiting an atom. After being excited, the qubit immediately relaxes, producing a single photon. The qubit energy can be tuned, thus altering the frequency of the output photons.



Tuneable microwave single-photon source

In addition to being a necessary part of prospective quantum computers, single photon sources can be used to shed light on the fundamental interactions between light and matter, which is vital for our understanding of quantum physics and the development of quantum and solid-state technologies. The team is hoping to build on its new single-photon source to develop the field of quantum information even further.

'WristWhirl' – a wrist-operated smartwatch

Checking email, Google Maps, and listening to music, are just a few things that a smartwatch can do – but what if your hands aren't free; for example, carrying groceries? A team at Dartmouth University in the US has come up with a solution – a smartwatch prototype that uses movements of the wrist wearing the watch as an always-available joystick to perform common touch screen gestures with one-handed continuous input.

WristWhirl was built from a 2-inch TFT display and a plastic watch strap augmented with 12 infrared proximity sensors and a piezo vibration sensor placed inside the wrist strap, which is connected to an Arduino DUE board

For a video of WristWhirl, visit: **https://youtu.be/JTPzeZGiI8w**

No Brexit for the second

The UK's National Physical Laboratory (NPL), in collaboration with LPL (CNRS, Université Paris 13) and LNE-SYRTE (CNRS, Observatoire de Paris and UPMC), has established a fully-functional fibre link between optical clocks based in the UK and France. The international fibre link, only the second of its kind in the world, will allow for the characterisation and comparison of optical clocks developed independently in the two countries, and will be used to help change the way we measure the second, the fundamental unit of time. The 800km long fibre passes through the Channel Tunnel with signal amplifiers at 10 stations along its length.

Optical clocks are the most accurate clocks in the world, losing no more than one second in the age of the Universe, 13.8 billion years. As they are the world's most accurate time-keeping devices, the only way to ensure that they are working is by comparison against other clocks of similar accuracy. Though comparison is possible on a local level, it is susceptible to local errors: if each clock were subject to exactly the same malfunction due to its location, it would not be possible to detect the defect locally. Thus, the wider the net of clocks, the more likely any discrepancy is to be detected.

AI angels or demons?

Amazon, Google, Facebook, IBM and Microsoft have announced that they will create a non-profit organisation that will work to advance public understanding of artificial intelligence technologies (AI) called Partnership on AI.

The objective of the Partnership is to address opportunities and challenges with AI technologies to benefit people and society. Together, the organisation's members will conduct research, recommend best practices, and publish research under an open license in areas such as ethics, fairness and inclusivity; transparency, privacy, and interoperability; collaboration between people and AI systems; and the trustworthiness, reliability and robustness of the technology. It does not intend to lobby government or policymaking bodies.

The rise of AI has led to dire warnings from eminent scientists, including reknowned Cambridge physicist professor Stephen Hawking. In a recent interview with the BBC he said:

'I believe there is no deep difference between what can be achieved by a biological brain and what can be achieved by a computer. It therefore follows that computers can, in theory, emulate human intelligence – and exceed it.

'That, he said, could lead to the eradication of disease and poverty and the conquest of climate change. But it could also bring us all sorts of things we don't like – autonomous weapons, economic disruption and machines that developed a will of their own, in conflict with humanity.

'In short, the rise of powerful AI will be either the best, or the worst thing, ever to happen to humanity. We do not yet know which.'

Smallest transistor ever

For more than a decade, engineers have been eyeing the finish line in the race to shrink the size of components in ICs. They knew that the laws of physics had set a 5nm threshold on the size of transistor gates among conventional semiconductors, about one-quarter the size of high-end 20nm-gate transistors now on the market… but, some laws are made to be broken, or at least challenged.

A research team at the US Department of Energy's Lawrence Berkeley National Laboratory has done just that by creating a carbon nanotube transistor with a working 1nm gate. For comparison, a strand of human hair is about 50,000nm thick.

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TechnoTalk

The high price of cleanliness

Mark Nelson

Cleanliness has its cost – to the environment and to your health. 50 years ago we ignored these drawbacks, but now there's no excuse. If you build electronic projects, you need to know the hidden hazards on your workbench and take proper precautions.

UNTIL THE 'SWINGING SIXTIES', carbon tetrachloride (CTC or 'carbon-tet') could be found in every kitchen and on every workbench. Sold in small bottles under the trade name Thawpit, carbon tetrachloride was a powerful proprietary stain remover that genuinely made oil and grease marks on clothes vanish. 'Thawpit removes dirty marks' was the slogan – and unlike other advertising mantras – this one was totally true. Those same solvent properties made CTC the favourite substance on every electronic workbench and in all radio and TV workshops for degreasing chassis, removing solder flux from PCBs and tackling all manner of other dirty jobs. No wonder electronicists sloshed it around with gay abandon (as we said in those days).

But CTC had a dark secret (and it *was* a secret, because few people had any idea that a product on unrestricted sale might have a danger). The chemical was (and of course still is) seriously dangerous if ingested, inhaled, or absorbed through the skin, leading potentially to liver cancer, toxic hepatitis and death. Like the other health hazards described in this article, the poisoning is cumulative, meaning that even low levels of exposure over long periods of time can be toxic.

Super substitute

By the late 1960s, CTC was phased out forcibly and replaced by 'Trike'. Yes, that's what we called it, although the correct name was trichloroethylene (alias 'TCE', 'Tricky' or 'Tri'). A British development pioneered by the Imperial Chemical Industries (ICI) conglomerate, Trike was the favoured replacement for CTC in electronics labs and unlike modern 'healthier' substitutes, it worked almost equally well. Indeed, trichloroethylene was so effective that it remained on sale until 2009 for specialised industrial applications. Used thoughtfully by competent practitioners it was very effective, but sadly not without risk. It is now considered carcinogenic, with harmful effects to the central nervous system, liver and kidney, especially for smokers, which is why it did not remain in use long.

Who's for IPA?

Sorry, not India Pale Ale. The 'improved' workshop replacement for Trike was isopropyl alcohol, also known as 'IPA', 'Isopropanol', 'dimethyl carbinol' or 'rubbing alcohol'. In its favour, it dissolves many oils, alkaloids, gums and natural resins. It's pretty good for cleaning passive parts such as contact pins, pickup heads, optical discs, the lenses in optical drives, PC screens and for removing thermal paste off ICs and heatsinks. On the minus side, probably its worst attribute is its flammability. It is also nowhere near as effective as Trike or CTC for degreasing or removing solder flux from PCBs but hey, life is always a compromise these days.

Other downsides? Yes. IPA is a skin irritant, so you should use protective gloves (although nobody does) and prolonged exposure (ingestion, inhalation, or skin absorption) can lead to headache, dizziness and, nausea, meaning that good ventilation is a must. So is IPA the answer to the proverbial maiden's prayer? Hardly – its chief advantage is its relatively low price and widespread availability.

Flawed fluid

Flammability and side effects are not the only disadvantages of IPA. The now-retired 'guru of cleaning' Ed Forrest points out that IPA is neither a very effective nor very versatile solvent. IPA's cleaning ability is good with human body oil and ionic salts but not much more, he asserts. IPA is not effective on mineral oils and most hand lotions, nor does it clean oils and greases very well. Because IPA does not evaporate very quickly, it can leave contamination or moisture behind in critical applications. Another characteristic is that it attracts moisture to itself, which is why the rubbing alcohol purchased at your local pharmacy is about 30 per cent water, he points out.

'There have been many important advances in the science of cleaning over the past three decades. The essential reality is IPA has been surpassed and replaced by safer and more effective chemicals,' he sums up. 'The final selection ... is a complex trade-off of many attributes: cost, storage, handling, purity, actual cleaning ability, drying time and worker safety – to name a few. The best choices are ultra-pure, fast-evaporating, non-flammable cleaners.'

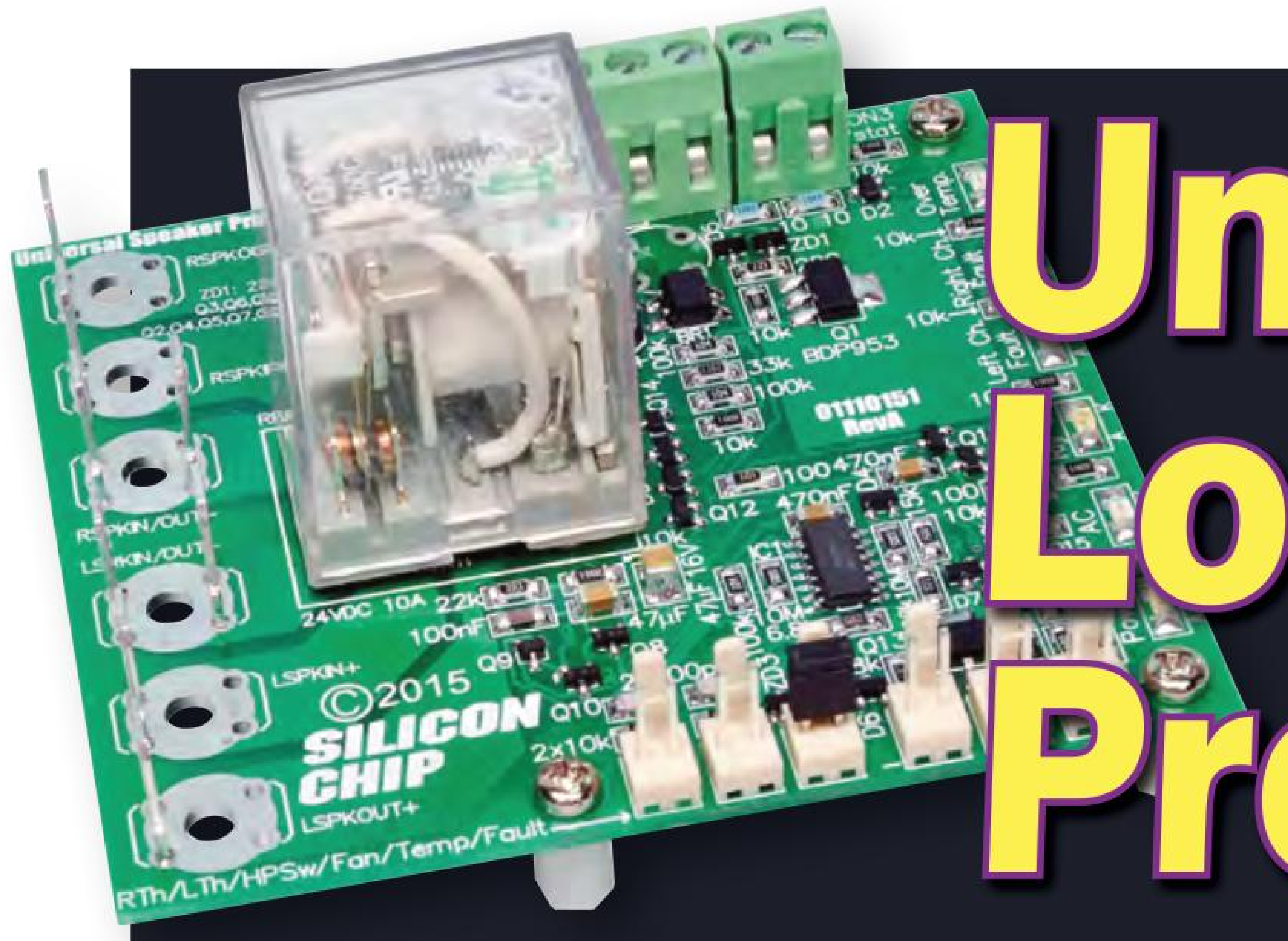
Eco-friendly

Today's smart solution or solvent of choice is a safe, non-ozone-depleting chemical developed by scientists at the 3M company and made under licence by a number of firms under trade names such as Novec and Cleanblast. Technically it is a hydrofluoroether (HFE)-based solvent that remains in the atmosphere for less than two weeks, being absorbed into the ground rather than remaining dissolved in the atmosphere. It is also non-flammable and fast evaporating, leaving no residue. What's not to like then? Well, the price is eye-watering (just look on eBay or Amazon for '3M Novec'). That's why you will not find this product at Maplin, CPC or other supply houses.

Solder fumes

Another underestimated health risk is the pleasant whiff of burnt resin you get when soldering. Personally, I no longer notice any smell these days, but maybe my nose is desensitised. Nevertheless, breathing these fumes is not good for you and prolonged exposure (seven hours a day, five days a week) could be more than just troublesome. People say that the additional flux required to create effective SMD solder joints means there are more fumes, but I have as little as possible to do with surface-mount devices.

Keeping a window open when you are soldering makes sense and if you're a heavy solderer, why not install a fan near your work area to keep the fumes away from your face. If you don't mind looking like Darth Vader, an industrial-grade fume filter, as used by spray painters, makes excellent sense and will not cost the earth. Look on eBay for '3M 7502' and you will find a professional respirator for £12. Don't waste money on a cheap dust mask; it will give no protection against organic vapours whatsoever.



Universal Loudspeaker Protector

By Nicholas Vinen

This extensively revised *Universal Loudspeaker Protector* module protects expensive loudspeakers from catastrophic faults in amplifiers. Plus, it mutes switch-on and switch-off thumps, disconnects the speakers if you plug in your headphones and has heatsink temperature sensing to control a cooling fan in the amplifier. It also has on-board LEDs to indicate various fault conditions.

ALL HIGH-POWER amplifiers should have an in-built *Loudspeaker Protector* that will disconnect the speakers if the amplifier develops a serious fault which could result in a high DC voltage being applied to the speaker(s). Without the *Loudspeaker Protector*, the resulting high current would damage the speaker and in the worst case, set the speaker on fire!

You can imagine the scenario: you have the volume pumped up to enjoy your favourite music and suddenly one speaker emits a loud *PFFTT*... and then, nothing. Maybe the other channel stays just as loud. But before you realise it you have a catastrophic fault, the damage is done; expensive damage.

Mind you, it could be a lot worse if you're having a party and you're not even in the room when the fault occurs – the speaker could catch fire, which can happen within seconds!

Some Hi-Fi amplifiers have PTC thermistors in series with the outputs to prevent speaker damage and fire. These work because the high current which flows during a fault causes them to heat up and thus increase in resistance, limiting the power delivered. However, because they are non-linear devices, PTC thermistors can seriously distort performance during normal operation of the amplifier.

Relays are much better in this regard, but even they can have a secondary effect on distortion performance. This is why we have been careful to verify that the relay used in this project does not have any significant effect.

Other roles played by the *Loudspeaker Protector* include muting any switch-on and switch-off thumps, disconnection of the speakers if the amplifier modules overheat (eg, due to being driven too hard), disconnecting the speakers when headphones are plugged in and running a small fan before the amplifier's heatsinks get too hot.

As noted above, we have included on-board indicator LEDs so you don't have to guess what's going on. These show the presence of DC and AC (mains) power, relay operation, left and right channel fault status and over-temperature fault status. This makes testing the module and verifying its normal operation much easier.

Features and specifications

- Fast speaker disconnection with a sudden-onset DC fault (typically <50ms)
- Compact PCB
- Operating voltage range: 15-55VAC or 22-50V DC (minimum 18VAC/24V DC if fan output used)
- Operating current: ~50mA (not including fan current)
- Switch-on and switch-off thump muting
- Temperature monitoring with overheat indicator and speaker disconnection
- Headphone speaker disconnection option using common 3PST sockets
- Temperature sensing with thermostats or NTC thermistors
- Fan switch-on at a preset heatsink temperature
- Six on-board LEDs and two optional off-board status LEDs

Don’t let this happen to you!

Without a *Loudspeaker Protector*, a serious fault in a high-power amplifier could cause enough current to flow through a speaker’s voice coil to set the speaker on fire. These three photos, taken at three-second intervals, illustrate just how quickly a fire can take hold once the cone ignites.

This design will run over a wide range of voltages without modification, and has simple supply wiring, partly because it has an on-board bridge rectifier; in many cases, one pair of wires from one of the transformer secondaries is all that’s required to power it. The PCB is compact because we have employed a fair proportion of surface-mount devices, which should prove relatively easy to install and solder.

Circuit description

The *Loudspeaker Protector* module monitors seven inputs to determine when to connect or disconnect the speakers or turn on the fan or various LEDs. These seven inputs are:

- AC power
- Left channel DC offset
- Right channel DC offset
- Left and right channel temperature-sensing thermistors (if fitted)
- Headphone socket switch (if fitted)
- Heatsink thermostat(s) (if fitted).

The full circuit is shown in Fig.1. The inputs mentioned above connect via CON1, CON3, CON4, CON5, CON9, CON13 and CON17. Let’s go through these in sequence.

One of the amplifier’s power supply transformer AC secondaries is connected to pin 3 of CON1. This voltage is applied to the emitter of NPN transistor Q3 and the base of NPN transistor Q4 via a 10kΩ resistor, with a 100kΩ pull-down to improve noise immunity.

If the voltage at pin 3 of CON1 is above about 0.7V, Q4’s base-emitter junction is forward-biased and so its collector sinks current, turning on AC sense indicator LED2. Similarly, if the voltage at this pin is below about –0.7V, Q3’s base-emitter junction is forward biased (it’s operating as a common-base amplifier) and it pulls current from the base of PNP transistor Q12, switching the latter transistor on and thus the result is the same – LED2 turns on.

So LED2 is on whenever the absolute voltage at pin 3 of CON1 is more than 0.7V, which is true most of the time when mains power is applied to the transformer. As soon as the mains supply is switched off, the voltage at pin 3 drops to zero and LED2 turns off within milliseconds.

When Q4 or Q12 are on, they not only power LED2 but they also sink current via D1 and the series 100Ω resistor. This discharges the connected 470nF capacitor and thus NPN transistor Q9 is off. It in turn allows the 47µF capacitor connected to its collector via a 100Ω resistor to begin charging.

After a few seconds, this capacitor has charged to 14V and Q10’s base-emitter junction becomes forward biased, because its emitter is limited to 13.5V, due to the voltage across zener diode ZD2 and regular diode D3. Q10 therefore switches on, sinking current from PNP transistor Q15’s base which in turn powers the relay coil. With the relay on, LED3 also illuminates (as well as any external LED connected to CON8).

While the relay switch-on is delayed by several seconds during the charging of the 47µF, it switches off almost immediately when power is removed, since Q9 discharges it via a 100Ω resistor, a much lower value than the 100kΩ charging resistor. Thus, the speakers are disconnected before the collapsing power supply can cause the amplifier modules to deliver a transient and cause a thump, regardless of how long the main power supply reservoir capacitor charge lasts.

Amplifier fault detection

Relay switch-off must be similarly fast should either power amplifier module (left or right channel) develop a fault which results in its output being pegged to a high positive or negative voltage – for example, a shorted output transistor. This is a bit tricky since normal output signals can contain significant excursions, eg, loud low-frequency bass.

The solution is to filter out the AC component of the signal from each channel with a simple RC low-pass filter comprising 22kΩ and 10kΩ resistors and a 47µF capacitor for each channel.

The filtered, attenuated signal is fed to transistors Q5, Q6 and Q13 (left channel) or Q7, Q8 and Q14 (right channel), which are arranged in the same manner as Q3, Q4 and Q12 as described above and thus are also triggered by voltages exceeding about

±0.7V. If either fault-detector channel is triggered, LED4 or LED5 illuminates and the 47µF time-delay capacitor is quickly discharged via D2 and its 10Ω series resistor, disconnecting the speakers from the amplifier.

We tested this filter arrangement using LTSPICE simulations to check both that normal audio waveforms will not cause false triggering and that a serious amplifier fault will result in a quick switch-off. For example, a 15Hz sinewave delivering 200W into an 8Ω speaker will not trigger this circuit, even with other higher-frequency, high-power signals mixed into it.

However, if the amplifier offset goes from 0V to either +40V or –40V and stays there indefinitely, the fault detection circuit triggers in approximately 20ms. The relay itself takes a little time to switch off too, but even taking this into account, the speakers should be disconnected in less than 50ms under these conditions.

Should the fault detection be triggered by, say, an extreme signal overload which is then removed, the speakers will be re-connected within a few seconds after amplifier operation returns to normal.

In addition, when the speakers are disconnected from the amplifier, the terminals are effectively shorted out, to blow out any arc which may occur between the relay contacts due to the high DC current being interrupted.

You might notice that there are empty pads on the PCB near the low-pass filter components. These were included for the connection of 100nF 100V capacitors across the 22kΩ resistors. Simulation shows that this speeds up fault detection by around 10%. However, they could potentially couple ground ripple voltage into the speaker outputs and thus affect distortion performance, so we decided to omit them from the final design.

Detecting other faults

Amplifier overheating can be detected by a normally-open thermostat bolted to each heatsink and wired across CON3. Multiple thermostats can be connected in parallel to monitor multiple heatsinks. When any one closes, the 47µF capacitor is discharged via D4 and thus the speakers are disconnected. When it cools down and opens, the speakers are re-connected after the normal delay.

However, this module also has provision to sense heatsink temperature using one or two 10kΩ NTC (negative temperature coefficient) thermistors. These are cheaper than thermostats and smaller, requiring only a single M3 screw for mounting. They are also more accurate (typically within around 1°C) and since they can sense a range of temperatures, they can be used to control a cooling fan which comes on at a lower temperature, to cool the heatsink and possibly avoid ever disconnecting the speakers, even though you may have the volume 'pumped up'.

Also, since the thermistor temperature thresholds are set using a simple resistive divider, you can easily change them to suit your needs. With thermostats, you are limited in choice of temperature thresholds and hysteresis.

The thermistor(s) connect via CON4 and/or CON5. They form a voltage divider across the 24V supply, in combination with a 10kΩ resistor to ground. At 25°C, this results in ~12V at the junction, increasing as the thermistor heats up.

Comparators IC1a-IC1d monitor these voltages. These are part of an LM339 quad low-power comparator. IC1a compares the voltage from the thermistor at CON4 to a reference voltage formed by a 15kΩ/5.6kΩ/100kΩ divider across the 24V supply. This voltage will vary with the supply rail, but so will the voltage from the thermistor, ie, it is a ratiometric comparison.

Pin 5 of IC1a is approximately 4.1V below the 24V rail. The specified thermistor has a beta of 3970. Using the calculator at: **www.daycounter.com/Calculators/Steinhart-Hart-Thermistor-Calculator.phtml**, we determine its resistance is 2070Ω at 65°C. We will therefore have a voltage that's 4.12V below the 24V rail at pin 4 of IC1a. So at this temperature, the output of IC1a will go low, sinking current through PNP transistor Q16.

Q16 operates as an emitter-follower, powering the optional 12V fan at CON6. Comparator IC1b works exactly the same way for the other thermistor, and since the open-collector outputs are joined together, the fan will turn on when either heatsink exceeds 65°C.

If either reaches 75°C, the associated thermistor resistance drops to 1477Ω. Thus, pin 8 of IC1c or pin 10 of IC1d will be just 3V below the 24V rail. Both non-inverting inputs (pins 9 and 11) are 2.98V below this rail, so above 75°C, the output of IC1c or IC1d will go low. Over-temperature indicator LED6 will then light and the 47µF time-delay capacitor will be discharged via D4, switching off RLY1.

Fig.1: the full circuit for the *Loudpeaker Protector*. Transistors Q3, Q4 and Q12 monitor the presence of AC power, while Q5/Q6/Q13 and Q7/Q8/Q14 monitor the left and right amplifier channel DC offsets in a similar manner. IC1 monitors the NTC thermistor resistance at CON4 and CON5 and either switches on a fan at CON6 or switches off the main speaker relay RLY1 if the temperature gets too high. Onboard rectifier BR1 and the 220µF filter capacitor provide a DC supply for the circuit while Q1 and ZD1 regulate the voltage to an average of around 24V DC. Similarly, Q2 and ZD3 provide a current-limited 12V supply for the optional cooling fan.

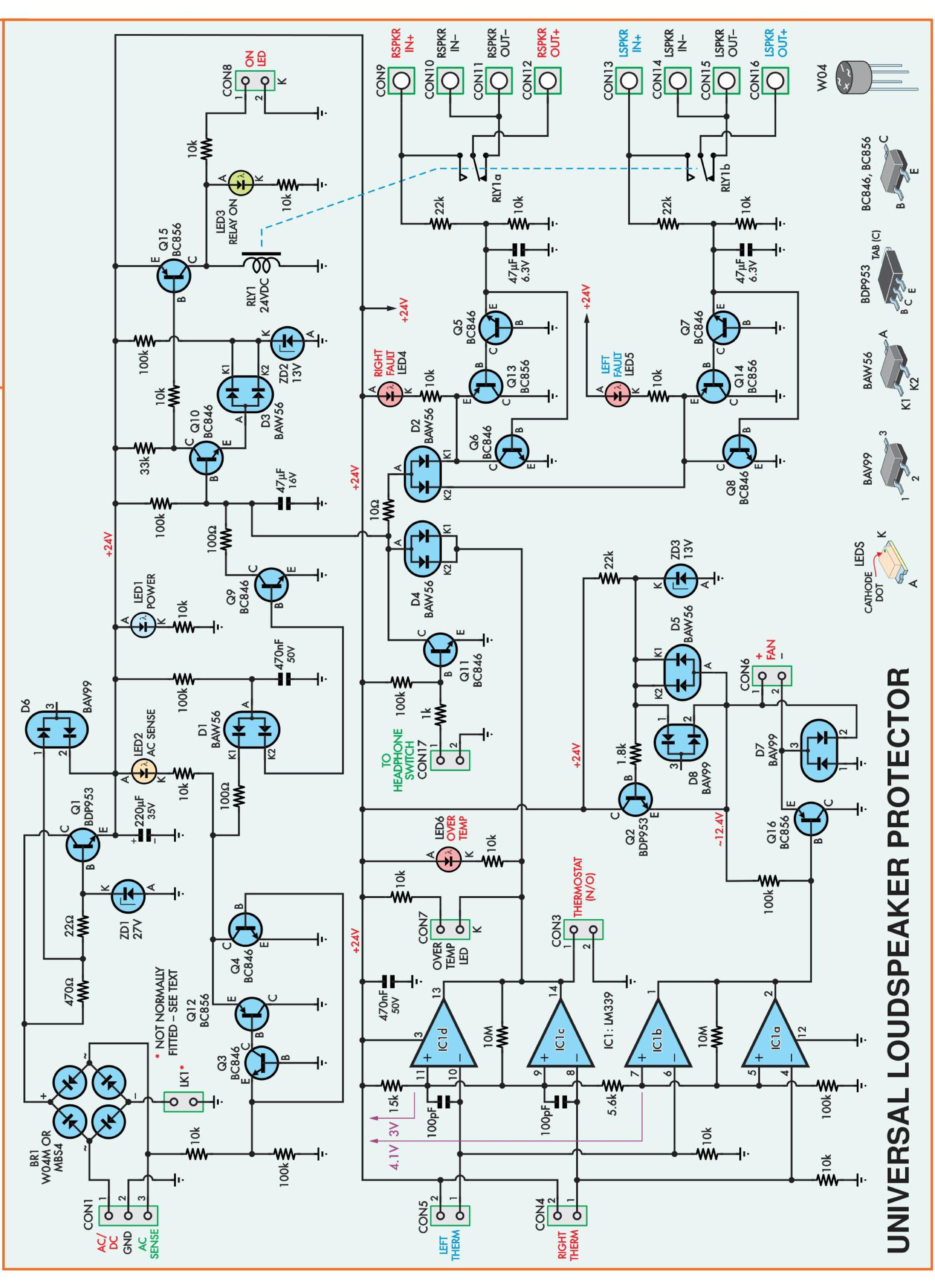
A 10MΩ resistor from the common IC1c/IC1d output (pins 13 and 14) to their common non-inverting input pins (9 and 11) provides a little hysteresis, so that the relay does not switch on and off rapidly. Once the relay is off, the heatsink temperature must drop by several degrees before it will switch back on. Similarly, the 10MΩ hysteresis resistor for IC1a/IC1b ensures that once the fan has switched on, the heatsink temperature must drop by a degree or two before it will switch back off.

The two 100pF capacitors filter out any RF picked up by the thermistor leads. If either or both thermistors are not connected, the associated pin will be pulled down to ground by the 10kΩ resistor and this will disable temperature monitoring for that channel.

Headphone switching

Generally, we want to disconnect the speakers when a headphone jack is inserted. The signal for the headphones is taken from before the speaker protector relay so that output is not affected.

Most jack sockets have a switched ground terminal for the sleeve which opens when a jack is inserted. This is wired to pin 1 of CON17 so that when a plug is inserted, the base of NPN transistor Q11 is pulled high via a 100kΩ resistor. Thus Q11 turns on, discharging the 47µF capacitor and switching RLY1 off. When the plug is removed, it switches on again after the usual delay. If this feature is not needed, CON17 is shorted out (eg, with a jumper shunt) to disable Q11.


CON1
AC/DC
GND
AC SENSE
BR1 W04M OR MBS4
LK1*
* NOT NORMALLY FITTED – SEE TEXT
D6 BAV99
Q1 BDP953
220µF 35V
ZD1 27V
22Ω
470Ω
LED2 AC SENSE
LED1 POWER
D1 BAW56
470nF 50V
100Ω
Q3 BC846
Q4 BC846
Q12 BC856
Q9 BC846
Q10 BC846
Q15 BC856
D3 BAW56
ZD2 13V
RLY1 24VDC
LED3 RELAY ON
CON8 ON LED
47µF 16V
+24V
10Ω
D2 BAW56
D4 BAW56
Q11 BC846
TO HEADPHONE SWITCH CON17
LED6 OVER TEMP
CON7 OVER TEMP LED
470nF 50V
IC1d
IC1c
IC1b
IC1a
IC1: LM339
10M
15k
100pF
5.6k
4.1V
3V
CON5 LEFT THERM
CON4 RIGHT THERM
CON3 THERMOSTAT (N/O)
Q2 BDP953
1.8k
D8 BAV99
D7 BAV99
D5 BAW56
ZD3 13V
CON6 FAN
~12.4V
Q16 BC856
RIGHT FAULT LED4
LEFT FAULT LED5
Q5 BC846
Q6 BC846
Q13 BC856
Q7 BC846
Q8 BC846
Q14 BC856
47µF 6.3V
22k
10k
100k
33k
1k
RLY1a
RLY1b
CON9 RSPKR IN+
CON10 RSPKR IN–
CON11 RSPKR OUT–
CON12 RSPKR OUT+
CON13 LSPKR IN+
CON14 LSPKR IN–
CON15 LSPKR OUT–
CON16 LSPKR OUT+
W04
BC846, BC856
BDP953 TAB (C)
BAW56
BAV99
LEDS
CATHODE DOT

UNIVERSAL LOUDSPEAKER PROTECTOR

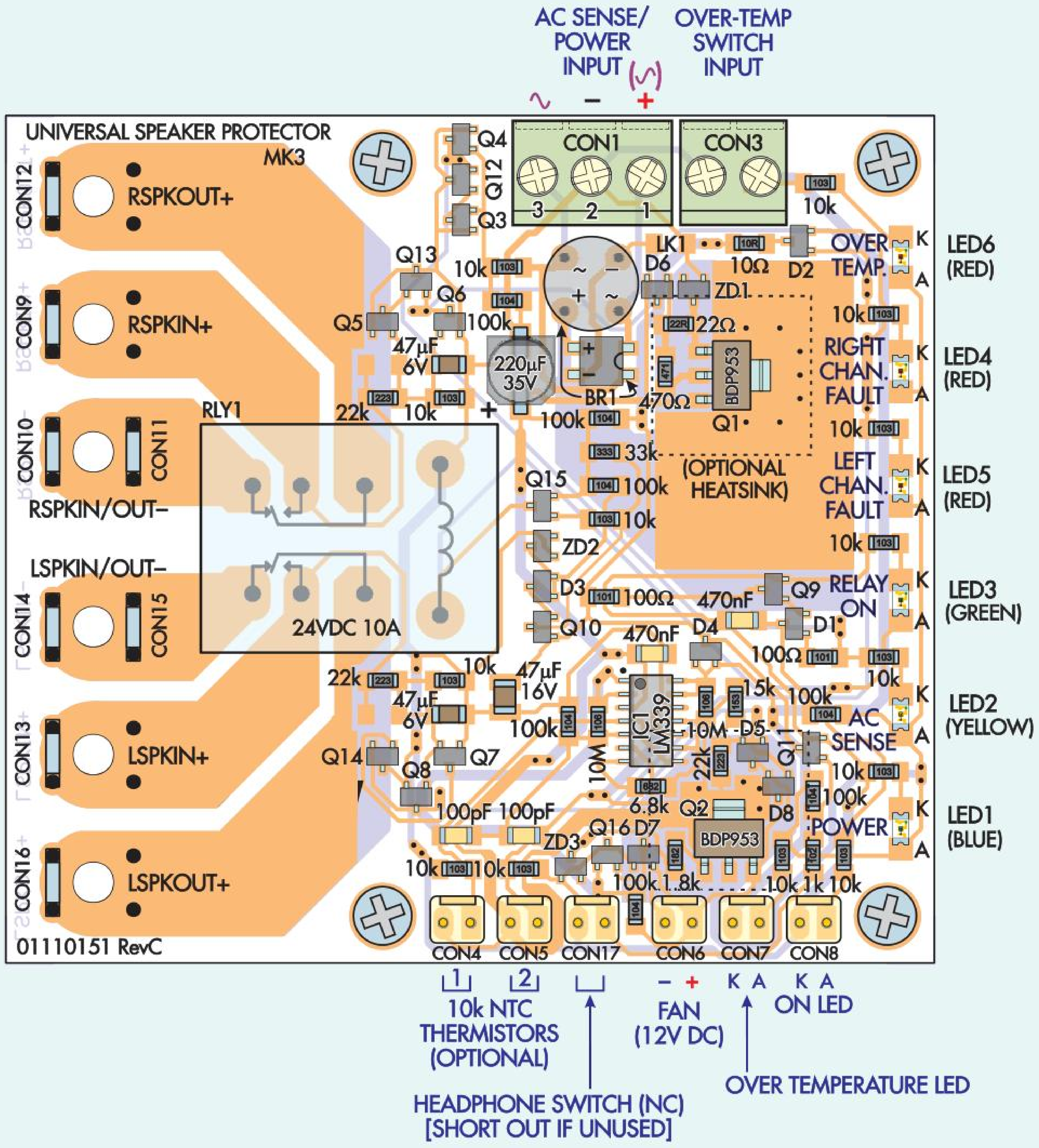

AC SENSE/ POWER INPUT
OVER-TEMP SWITCH INPUT
UNIVERSAL SPEAKER PROTECTOR MK3
CON1
CON3
CON12
RSPKOUT+
CON9
RSPKIN+
CON10
CON11
RSPKIN/OUT–
LSPKIN/OUT–
CON14
CON15
CON13
LSPKIN+
CON16
LSPKOUT+
RLY1
24VDC 10A
01110151 RevC
220µF 35V
BR1
BDP953
Q1
(OPTIONAL HEATSINK)
IC1 LM339
OVER TEMP.
RIGHT CHAN. FAULT
LEFT CHAN. FAULT
RELAY ON
AC SENSE
POWER
LED6 (RED)
LED4 (RED)
LED5 (RED)
LED3 (GREEN)
LED2 (YELLOW)
LED1 (BLUE)
CON4
CON5
CON17
CON6
CON7
CON8
10k NTC THERMISTORS (OPTIONAL)
HEADPHONE SWITCH (NC) [SHORT OUT IF UNUSED]
FAN (12V DC)
ON LED
OVER TEMPERATURE LED

Fig.2: use this layout diagram to build the *Loudspeaker Protector*. Fit the SMDs first, followed by the remaining components in order of ascending height. BR1 and the 220µF electrolytic capacitor can be either SMD or through-hole parts. It's recommended to fit a heatsink where shown if the fan output is being used. Take care with LED orientation; if in doubt, use a DMM to check which end is the cathode. LK1 is normally not fitted (see text).

Attaching non-solder spade lug connectors

Fig.3 (right) shows how double-ended non-solder spade lugs are mounted. Each lug is secured using an M4 x 10mm screw, a flat washer (which goes against the PCB pad), an M4 star lockwasher and an M4 nut.

The trick to installing them is to first do the nut up finger-tight, then rotate the spade lug assembly so that it is at a right-angle to the PCB. A screwdriver is then used to hold the M4 screw and the spade lug stationary while the nut is tightened from below using an M4 socket and ratchet.

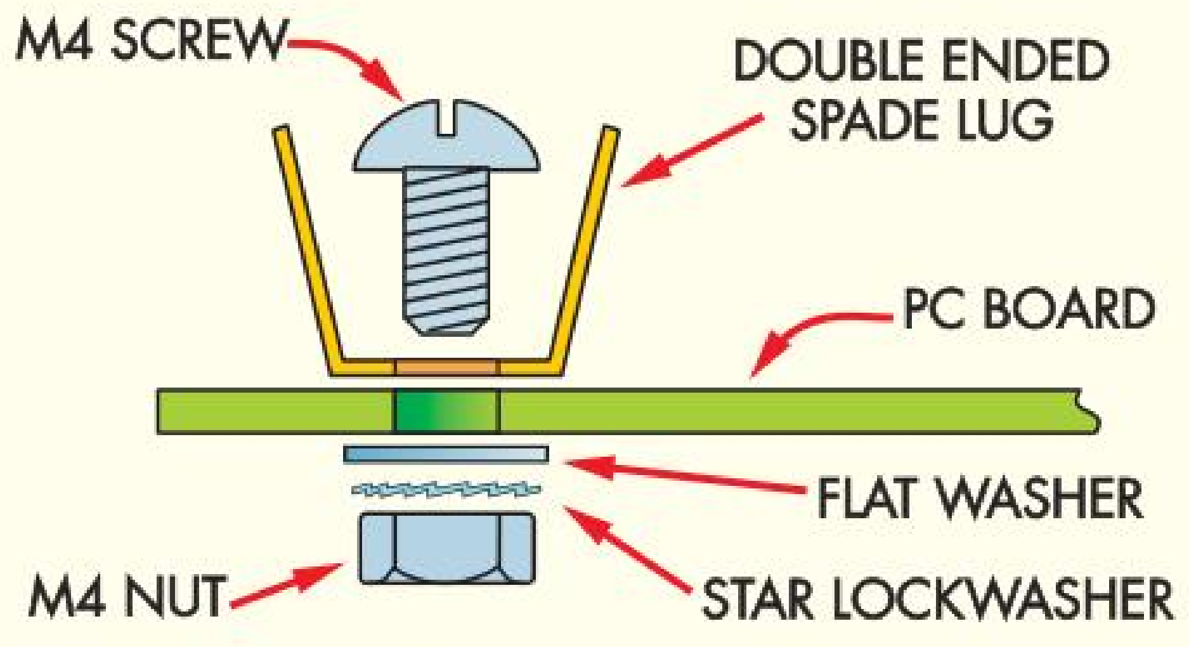

M4 SCREW
DOUBLE ENDED SPADE LUG
PC BOARD
FLAT WASHER
M4 NUT
STAR LOCKWASHER

Fig.3: attach the six double-ended spade lugs to the PCB as shown in this diagram.

Do the nut up nice and tight to ensure a good connection and to ensure that the assembly does not rotate.

Power supply

The easiest way to power this unit is from the transformer winding(s) that are used to power the amplifier modules. One end goes to pin 3 of CON1, for both AC sensing and connection to bridge rectifier BR1, while pin 2 of CON1 goes to ground/earth, as shown in Fig.5. This results in half-wave rectification, giving a pulsating DC voltage at the positive terminal of BR1.

This charges the 220µF capacitor via NPN transistor Q1. The 27V zener diode at its base is biased from the output of BR1 and prevents the 220µF capacitor charge from exceeding 27V, as ZD1 shunts Q1's base drive above this voltage. While the diodes in BR1 are forward-biased, the voltage in this capacitor is maintained via Q1. The rest of the time, this capacitor supplies the load current and recharges on the next mains cycle.

The voltage drop across Q1 results in heat dissipation of less than 1W during normal operation, or around 2W with a fan attached and running (drawing around 100mA). The PCB acts as a heatsink to safely dissipate this heat. Q1 is rated for 5W dissipation as long as the PCB temperature is kept below 100°C.

With the copper plane provided, junction-to-ambient thermal resistance is about 40°C/W so, in theory at least, no heatsink is required. **In practice, Q1 gets very hot to the touch if the board is driving a fan, so we strongly recommend you glue a small heatsink on top of Q1 if connecting a fan.** There are more details on this below.

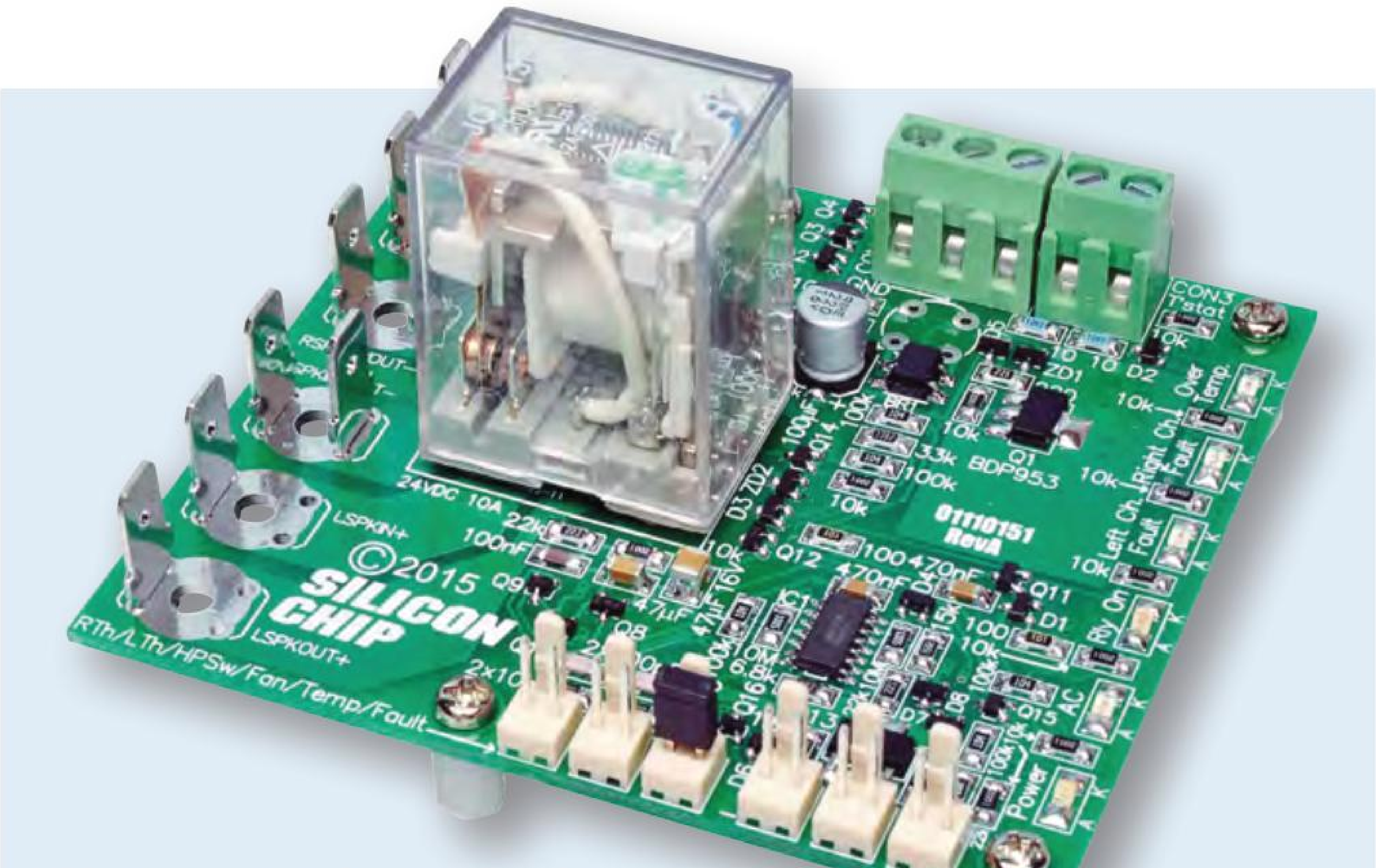
Dual series diode D6, in combination with the 22Ω base resistor, limits Q1's base current to 0.6V / 22Ω = 27mA, which in combination with its beta of around 100 provides a peak collector current of around 3A. This is close to its continuous rating of 3A and well below its 10ms peak rating of 5A.

If the unit is run from a centre-tapped transformer secondary with an AC voltage less than 35V-0-35V, both ends of the winding should be connected to CON1 (pins 1 and 3), giving full-wave rectification and 100Hz recharge of the 220µF capacitor. Otherwise, the ripple may be so great that RLY1 can't remain latched over the whole mains cycle.

With higher supply voltages this is not only unnecessary, but will likely increase dissipation in Q1. The key point is that the voltage across the 220µF capacitor should not drop below about 18V because RLY1's 'must operate' voltage is 16.8V.

Powering a fan

Most small DC fans run from 12V, so we've provided a 12V current-limited supply. This can be bypassed if a 24V type is used. Use a 24V fan if you can get a suitable type, since the fan will


This view shows the completed prototype *Loudspeaker Protector*. Note that you can either use PCB-mounting spade lugs as shown here or use double-ended chassis-mounted types (see panel).

receive more power and less will be dissipated in the *Loud Speaker Protector* power supply. Either way, the fan negative terminal is pulled to ground to turn the fan on or left floating to turn it off.

The ~12V rail is derived by NPN transistor Q2 from the 24V rail in a similar manner to the way that the 24V rail itself is derived by Q1. The 1.8kΩ base resistor, in combination with dual series diode D8 limits its base current to 0.6V / 1.8kΩ = 0.33mA, which, with a beta of 350, gives a maximum collector current of just over 100mA.

This protects Q1 and Q2 in case the fan terminals are shorted out. It also protects both transistors against excessive dissipation should the fan try to draw more than 100mA (as many 12V fans would). Basically, if that happens, the supply voltage will drop and it will simply run slower.

Diodes D5, and D7 absorb any inductive spikes which may be generated by the fan motor, especially when it is switched off, and prevent Q16's base-emitter or emitter-collector junctions from becoming reverse-biased.

If a fan is to be used, dissipation in Q1 will be lower if the module is driven from a centre-tapped low-voltage transformer winding of at least 18V-0-18V. With lower voltages, depending on the fan current draw, supply ripple may be too high for the unit to operate properly. In this case, you have to run the unit from the higher voltage windings on the transformer, as shown in Fig.5.

If driving a fan and running the unit off a much higher voltage transformer secondary, it's a good idea to fit a small heatsink to Q1, as explained earlier and described below.

If using a 24V fan, ZD3 should be omitted and the nearby 22kΩ resistor replaced with a 0Ω resistor (or a wire link).

Changing thresholds

If using NTC thermistors, the temperature thresholds can be changed by varying the value of two resistors. As explained above, the fan will normally switch on at 65°C (T_{FAN}) and the speakers are disconnected at 75°C ($T_{OVERHEAT}$).

Let's say you want T_{FAN} = 60°C and $T_{OVERHEAT}$ = 70°C instead. First, calculate the expected NTC thermistor resistance at these temperatures using the website listed previously: **www.daycounter.com/Calculators/Steinhart-Hart-Thermistor-Calculator.phtml**

Plug in beta = 3970, R1 = 10,000Ω, T1 = 25°C and T2 = 60°C to get R_{FAN} = 2468.7Ω. For T2 = 70°C we get $R_{OVERHEAT}$ = 1744.4Ω.

Since the reference voltage divider string has a 100kΩ resistor at the bottom, compared to the 10kΩ divider resistor for the NTC thermistors, the total value of our two new resistors (to replace the 5.6kΩ and 15kΩ resistors) will need to be R_{FAN} × 10, ie, 24,687Ω (R_{TOTAL}).

We can now calculate the new value for the 15kΩ resistor as (100,000Ω + R_{TOTAL}) × $R_{OVERHEAT}$/($R_{OVERHEAT}$ + 10,000Ω) = 18,519Ω. 18kΩ is close enough. The 5.6kΩ resistor is then replaced with a value of 24,687Ω – 18,000Ω = 6687Ω, which is close to 6.8kΩ. Substitute different thermistor resistance values into these formulae to calculate the required components for other temperatures.

Construction

The *Loudspeaker Protector* module is built on a double-sided PCB coded 01110151 (measuring 88 × 79mm) and is available from the *EPE PCB Service*. Most of the components are SMDs. The exceptions are the connectors, RLY1 and optionally, bridge rectifier BR1 and the 220µF electrolytic capacitor. Fig.2 shows the assembly details.

Start with the sole IC, comparator IC1. Locate its pin 1; this will normally be indicated by a dot, divot or failing that, a bevelled edge. Rotate the IC so that pin 1 is at upper left, as shown. Tack-solder one pin, then check that all the other pins are properly centred over their pads. You can either solder them individually or you can add flux paste down both sides of the IC and then use a wave-soldering technique.

Once all the pins have been soldered, check for bridges between them and use flux paste and solder wick to remove any bridges you find.

The next job is to mount the 27 SOT-23 package transistors and diodes. These are quite small, but the pins are spaced fairly far apart. The orientation of each is obvious due to the fact that they have one pin on one side and two on the other, but do be careful not to get the six different types of components mixed up and make sure they are not fitted upside-down – ie, their leads should be in contact with the PCB pads.

The basic technique is the same as for the IC – tack solder one pin, check the positioning, solder the other two pins and then refresh the initial solder joint with a little flux paste or added solder.

The two larger BDP953 transistors can be soldered in place now. These are in SOT-223 packages which do an excellent job of transferring heat to the PCB due to their large, thin tabs on which the silicon die is mounted.

The easiest technique (excluding hot-air or IR reflow) is to put a little flux paste on the large pad, then tack the part down at one of the smaller end pins. You can then solder the large tab; it will take a little while before the part and PCB heat up sufficiently to form a proper solder joint, but the flux paste should help the solder flow under the tab. You then immediately solder the centre small pin

Parts List: Loudspeaker Protector

1 double-sided PCB available from the *EPE PCB Service*, coded 01110151, 88 × 79mm
8 6.3mm PCB-mounting spade terminals, 5mm pitch (CON9-CON16) OR
6 double-ended chassis-mounting spade terminals with M4 × 10mm machine screws, shakeproof washers, flat washers and nuts
1 3-way terminal block, 5.08mm pitch (CON1)
1 2-way terminal block, 5.08mm pitch (CON3)
6 2-way polarised headers, 2.54mm pitch (CON4-CON8, CON17)
1 24V DC coil, 10A DPDT cradle relay with integral LED (RLY1)
4 M3 tapped spacers
4 M3 × 6mm pan-head machine screws
1 shorting block
2 10kΩ lug mounting NTC thermistors
1 12V or 24V DC fan (optional)
1 9V battery (for testing)
1 or 2 small finned heatsinks with adhesive pads (optional, see main text)
Various lengths of hook-up wire and header plugs as required

Semiconductors
1 LM339 comparator (SOIC-14) (IC1)
2 BDP953 100V 3A high-gain NPN transistors (SOT-223) (Q1,Q2)
9 BC846 NPN transistors (SOT-23) (Q3-Q11)
5 BC856 PNP transistors (SOT-23) (Q12-Q16)
1 27V 0.25W zener diode (SOT-23) (ZD1)
2 13V 0.25W zener diodes (SOT-23) (ZD2,ZD3)
1 400V 0.5A SMD bridge rectifier, MBS4 type (BR1) OR
1 W04 1A bridge rectifier (BR1)
5 BAW56 dual common anode diodes (SOT-23) (D1-D5)
3 BAV99 dual series diodes (SOT-23) (D6-D8)
1 high-brightness blue LED, 3216/1206 size (LED1)
1 high-brightness yellow LED, 3216/1206 size (LED2)
1 high-brightness green LED, 3216/1206 size (LED3)
2 high-brightness red LEDs, 3216/1206 size (LED4,LED5)
1 high-brightness amber LED, 3216/1206 size (LED6)
1 or 2 chassis-mounting LEDs for status indication (optional, see main text)

Capacitors (3216/1206 unless stated)
1 220µF 35V SMD or through-hole electrolytic, up to 8mm diameter
2 47µF 6.3V X5R
1 47µF 16V X5R (3224/1210 or 3216/1206 size)
2 470nF 50V X7R
2 100pF 50V C0G

Resistors (all 3216/1206, 0.25W 1%)
2 10MΩ
7 100kΩ
1 33kΩ
3 22kΩ
1 15kΩ
14 10kΩ
1 5.6kΩ
1 1.8kΩ
1 1.8kΩ 0.25W through-hole (for testing)
1 1kΩ 0.25W through-hole (for testing)
1 1kΩ
1 470Ω 0.5W
2 100Ω
1 22Ω
2 10Ω (one optional for LK1)

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(which is connected electrically to the tab) and finally the two outer pins.

Fitting the LEDs

There are five different colour LEDs and the first step before soldering each one is to verify its polarity. Use a DMM set on diode test mode and probe both ends of the LED package. When it lights up, the red probe is on the anode and the black probe on the cathode. The polarity is marked on the PCB and shown in Fig.2, so solder it to the appropriate pad with the correct orientation.

Often, the cathode is marked with a green dot – but not always, so be careful!

Since LED1 is blue and has a forward voltage of more than 3V, depending on your DMM it might not light up either way around. In this case you'll either have to trust the cathode marking or use a 9V battery with a series current-limiting resistor and a couple of short lengths of wire to probe it.

Solder them using the usual method of tacking down one end, soldering the other and then refreshing the first. Try to solder them with the base flat on the PCB.

The resistors and ceramic capacitors can now be mounted using the same basic technique. The resistors will be printed with a 3-digit or 4-digit code indicating their value (eg, 10kΩ = 103 or 1002) while the capacitors will not have any markings and you will have to check the packaging. **Make sure you don't get the 47µF 16V capacitor mixed up with the two 47µF 6.3V capacitors; the former is likely to be bulkier.**

Similarly, the 470nF capacitors will be thinner than the 47µF capacitors, and the 100pF ones thinner still.

Fit the electrolytic capacitor next, oriented as shown in Fig.2. It will normally have a bevelled base indicating the positive end and a black stripe on the negative end of the can. Solder its two metal pins similarly to the ceramic capacitors. You can use a regular through-hole electrolytic if you prefer, as mounting holes are provided. In this case, the longer lead goes though the pad towards the bottom of the board (ie, positive).

Similarly, the bridge rectifier can be an SMD or W02/W04 through-hole type. The SMD type will have a notch at the right-hand end (between the two AC terminals) while the through-hole type has a '+' printed above one lead (longer than the others) which goes in the pad indicated on the PCB. There's no need to fit both bridges.

Solder the polarised pin headers in place next, oriented as shown, followed by the two terminal blocks, with their wire entry holes towards the top of the board. Note that they are not dovetailed, ie, they're fitted separately.

The spade lugs are now soldered in place in the positions shown in Fig.2. Two are required for the negative-polarity speaker terminals, but only one for the positive-polarity terminals. Try to solder them in at right angles to the PCB but don't hold them while soldering as they get extremely hot!

Alternatively, you can attach chassis-mount spade lugs to the PCB

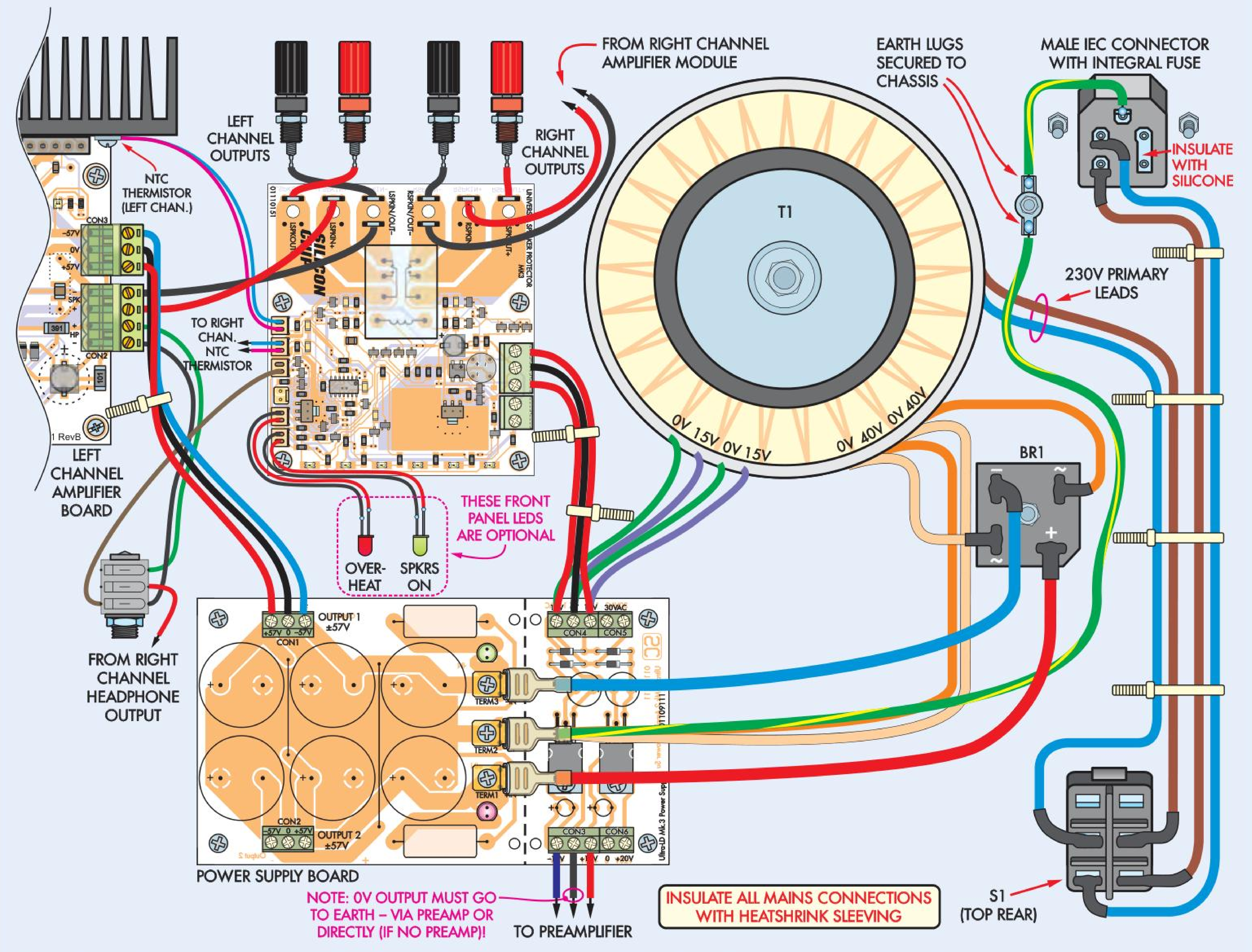

LEFT CHANNEL OUTPUTS
RIGHT CHANNEL OUTPUTS
FROM RIGHT CHANNEL AMPLIFIER MODULE
EARTH LUGS SECURED TO CHASSIS
MALE IEC CONNECTOR WITH INTEGRAL FUSE
INSULATE WITH SILICONE
NTC THERMISTOR (LEFT CHAN.)
CON3
–57V
0V
+57V
SPK
HP
CON2
1 RevB
LEFT CHANNEL AMPLIFIER BOARD
TO RIGHT CHAN. NTC THERMISTOR
LSPKOUT
LSPKIN+
LSPKIN/OUT–
RSPKIN/OUT–
RSPKIN
SPKOUT+
SILICON CHIP
UNIVERSAL SPEAKER PROTECTOR MK3
01110151
T1
230V PRIMARY LEADS
0V 15V 0V 15V
0V 40V 0V 40V
BR1
THESE FRONT PANEL LEDS ARE OPTIONAL
OVER-HEAT
SPKRS ON
FROM RIGHT CHANNEL HEADPHONE OUTPUT
OUTPUT 1 ±57V
+57V 0 –57V
CON1
30VAC
CON4
CON5
TERM3
TERM2
TERM1
CON2
–57V 0 +57V
OUTPUT 2 ±57V
CON3
CON6
0 +20V
Ultra-LD Mk.3 Power Supply
POWER SUPPLY BOARD
NOTE: 0V OUTPUT MUST GO TO EARTH – VIA PREAMP OR DIRECTLY (IF NO PREAMP)!
TO PREAMPLIFIER
INSULATE ALL MAINS CONNECTIONS WITH HEATSHRINK SLEEVING
S1 (TOP REAR)

Fig.4: here's how to connect the *Loud Speaker Protector* module when the transformer has a low-voltage set of secondaries. In this case, they're being fed to a power supply board to provide regulated ±15V rails for a preamplifier. Note that in this case, the *Loud Speaker Protector* will only work if the transformer centre tap is connected to earth via the regulator board and preamp. Note also the single wire from the headphone socket to the module; this is done to avoid an earth loop (the ground connection is provided by the power supply).

using M4 × 10mm machine screws, nuts and washers, as shown in Fig.3. Use shakeproof and flat washers to ensure good electrical connections between the spade lugs and the PCB pads and to ensure that they don't come loose.

All that's left is the relay. Ensure this is pushed all the way down onto the PCB before soldering its pins. It will only go in one way.

Changing component values

Remember that you may want to change a few of the components to suit your application. These include: the 15kΩ and 5.6kΩ resistors if you are changing the temperature thresholds and ZD3 and its associated 22kΩ resistor if using a 24V fan.

Note that LK1 is normally NOT fitted. Fit LK1 if and only if both the following are true: the transformer winding powering the module is not connected to earth or anything else (including any other taps on the same winding) and the total winding voltage connected to the unit is no more than 24V. You can use a 10Ω SMD resistor for LK1 if required. Basically, if you're unsure as to whether or not you need LK1, leave it out!

Fitting a heatsink

While it certainly won't hurt to attach a small heatsink to Q1, as mentioned earlier, it isn't strictly necessary unless you are running a fan. Q2 typically dissipates less than 1.5W, but it also has a smaller copper pad on the PCB and will get pretty hot when the fan is running, so you may want to put a small heatsink on it too.

Just about any small finned heatsink will work. We used a small anodised aluminium heatsink on our prototype. This is designed to be attached to the top of a 14-pin DIP IC (or similar). We got it from Rockby (Stock No. 26001) and attached it using a piece cut from an adhesive silicone insulating washer.

The Jaycar HH8580 pin grid array heatsink should also be suitable and comes with an adhesive pad pre-attached. Simply peel off the backing tape and press it down hard on top of Q1 and it should stay there. There's less room around Q2, so you'd have to offset it a bit, but the same comment applies.

Testing

Thanks to the on-board indicator LEDs, testing the module is pretty simple. First, place a shorting block on CON17.

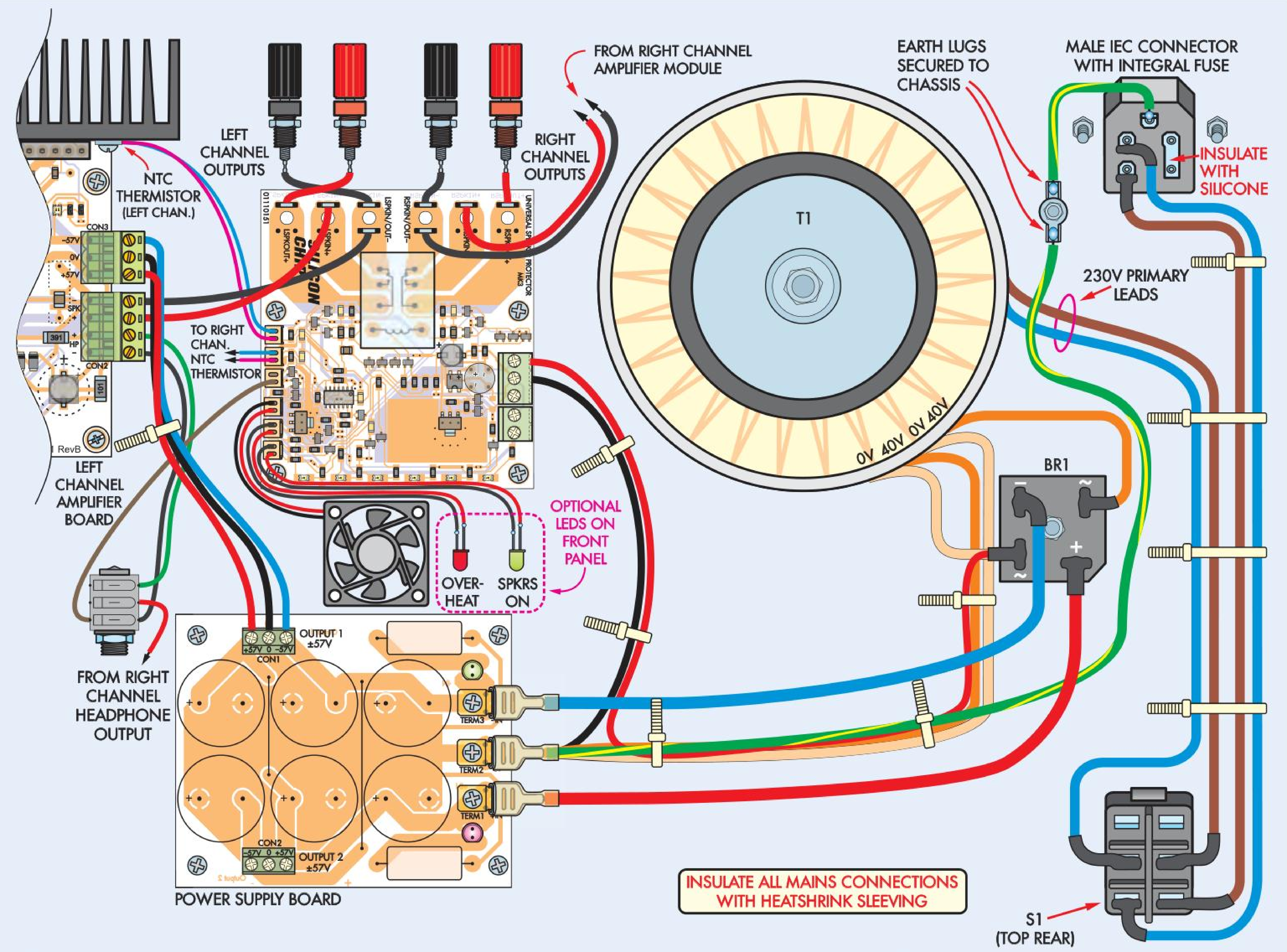

LEFT CHANNEL OUTPUTS
RIGHT CHANNEL OUTPUTS
FROM RIGHT CHANNEL AMPLIFIER MODULE
EARTH LUGS SECURED TO CHASSIS
MALE IEC CONNECTOR WITH INTEGRAL FUSE
INSULATE WITH SILICONE
NTC THERMISTOR (LEFT CHAN.)
T1
230V PRIMARY LEADS
CON3
–57V
0V
+57V
SPK
HP
CON2
RevB
TO RIGHT CHAN. NTC THERMISTOR
LSPKOUT+
LSPKIN+
LSPKIN/OUT–
RSPKIN/OUT–
RSPKIN+
RSPKOUT+
UNIVERSAL SPEAKER PROTECTOR MK3
01110151
LEFT CHANNEL AMPLIFIER BOARD
0V 40V 0V 40V
BR1
OPTIONAL LEDS ON FRONT PANEL
OVER-HEAT
SPKRS ON
FROM RIGHT CHANNEL HEADPHONE OUTPUT
OUTPUT 1 ±57V
+57V 0 –57V
CON1
TERM3
TERM2
TERM1
CON2
–57V 0 +57V
OUTPUT 2 ±57V
POWER SUPPLY BOARD
INSULATE ALL MAINS CONNECTIONS WITH HEATSHRINK SLEEVING
S1 (TOP REAR)

Fig.5: here's how to wire up the *Loud Speaker Protector* module so that it runs off the same transformer secondary as the power amplifier module(s). This will be necessary if the transformer only has the one set of secondaries (eg, in an amplifier with no preamp) or if you want the extra current to run a fan. Only one pair of supply wires is required unless the transformer secondary voltage is below 35V-0-35V. Note how the supply wiring is routed – this is to minimise any hum radiation due to the pulsating current draw of the unit.

Then hook up a source of medium-voltage AC or DC power to pins 1 and 2 of CON1 (middle and right-hand terminals, looking at the board as shown in Fig.2). If using DC, ensure the negative terminal is connected to pin 2, otherwise the supply will be shorted out by BR1.

Ideally, use 18-25VAC or ~30V DC. A series resistor of say 100Ω 5W can be connected to protect the supply and PCB in case of a construction error.

Apply power and check that LED1 (Power) lights. None of the other LEDs should light yet. If possible, measure the supply current (eg, by measuring the voltage across the safety resistor). You should get a reading of around 10mA. If the LEDs do not light up as expected, or the current drain is excessive, switch off and check for soldering or component placement mistakes.

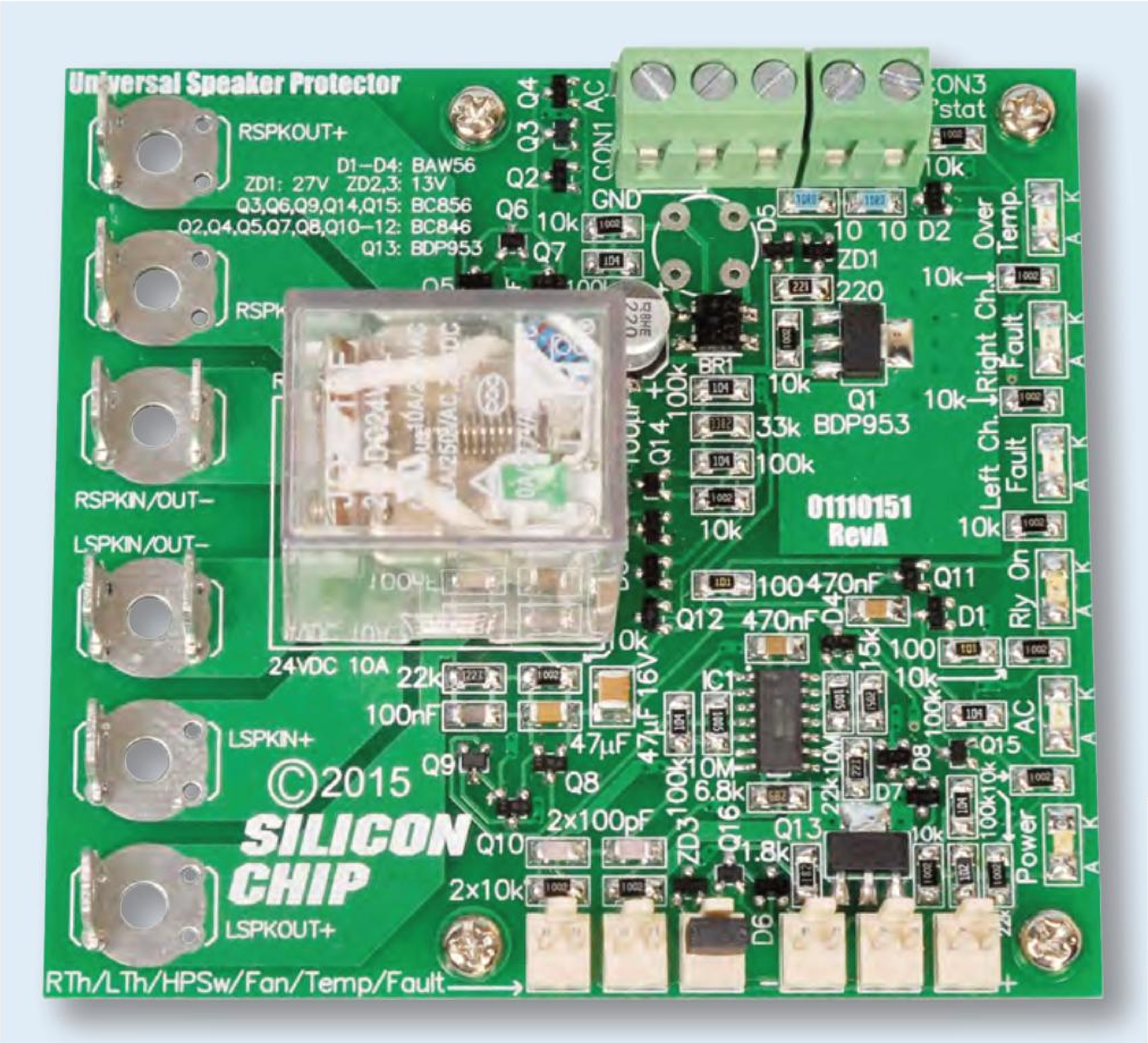
Assuming it all checks out fine, next measure the voltage across the electrolytic capacitor by touching the DMM's probes to the pads on the top of the PCB. If the incoming supply voltage is high enough for the unit to attain regulation, you should get a reading close to 27V. Now temporarily connect a convenient resistor (eg, 1kΩ 0.25W) between pins 1 and 3 of CON1, eg, by touching it across the two screw heads.

You should see LED2 (AC presence, yellow) light up when it is connected and LED2 should switch off immediately upon removal. Hold it in place for a few seconds and RLY1 should click on. At the same time, LED3 (Relay On, green) should light up. Remove the resistor and the relay should immediately turn off, along with LED3.

Power down and move the supply lead from pin 1 of CON1 (righthand end) to pin 3 (lefthand end). Power back on and wait for the relay to switch on. Then connect a spare 9V battery between supply ground (ie, pin 2 of CON1) and the LSPKIN+ terminal. LED4 (Left Channel Fault, red) should immediately light up and the relay should click off, along with LED3. Reverse the polarity of the battery and check that the same thing happens.

Now perform the same tests, but this time with the RSPKIN+ terminal. LED5 (Right Channel Fault, red) should light and the relay should again click off for both polarities.

If using a fan, connect it up now, then clip a 1.8kΩ resistor across one of the thermistor terminals. The fan should switch on but RLY1 should remain engaged and LED3 should not go out. Test the other thermistor terminal; it should



Here's another view of the fully-assembled prototype PCB. Be sure to install all the SMDs before installing the larger through-hole parts (see text).

Temperature sensors

Temperature sensors are variously called 'thermostat switches', 'thermal cutouts' and 'thermal circuit breakers' and are available in a range of trip temperatures from 50-100°C. Both NO and NC (normally-closed) temperature sensors are available, but the temperature sensor used with this unit must be a normally open (NO) type.

A thermal cutout rated at 70°C is available from Jaycar (ST3833). Alternatively, the Altronics S5591 is rated at 60°C.

behave the same way. Now do the same test on both terminals with a 1kΩ resistor. In both cases, RLY1 and LED3 should switch off and LED6 (Over Temperature, red) should light.

You can also check that shorting out the terminals of CON3 has the same effect, ie, RLY1 and LED3 switch off and LED6 lights.

Installation

The unit mounts in an amplifier chassis on four tapped spacers. Mark out the holes using the PCB as a template and drill them to 3mm. The basic wiring arrangement is shown in Figs.4 and 5. Fig.4 shows the arrangement when the transformer has suitable low-voltage secondaries, while Fig.5 shows the wiring when powering the unit from the same transformer secondaries as the amplifier module(s).

Note that high AC and DC voltages are present in amplifiers – be careful!

Use heavy-duty figure-8 cable for the loudspeaker connections. It doesn't matter if you swap the left and right channels around if it simplifies the wiring, but either way, ensure that the polarity (±) is correct. You can check by using a DMM to test for continuity between the LSPKIN– and RSPKIN– terminals and chassis earth (once the power amplifier supply wiring is complete).

Note the way we've shown the power supply wiring in Fig.5. This minimises the AC magnetic field around the wires. Also note that the AC supply connection must go to pin 3 of CON1 as shown. For a centre-tapped connection (as in Fig.4), use three lengths of hook-up wire twisted together and/or encapsulated in heatshrink tubing. The power supply current is normally 50-150mA, so medium/light-duty wire is OK.

If using thermostat(s), wire these in parallel to CON3. Their polarity does not matter. If using NTC thermistors, connect these to CON4 and CON5 as shown in Figs.4 and 5. The thermistors are also non-polarised.

To enable speaker disconnection when headphones are inserted, simply run a single wire from the switched terminal on the jack socket to the relevant terminal of the headphone switch connector (CON17) on the PCB as shown. The ground connection is made through the power supply wiring. If not using this feature, place a shorting block across this header instead.

Indicator LEDs

The two front-panel indicator LEDs are optional and you can fit none, one or both. No series resistor is needed because 10kΩ resistors are already on the PCB. These will supply around 2mA, which is sufficient for high-brightness LEDs, but you can reduce the value if necessary, to drive less efficient LEDs.

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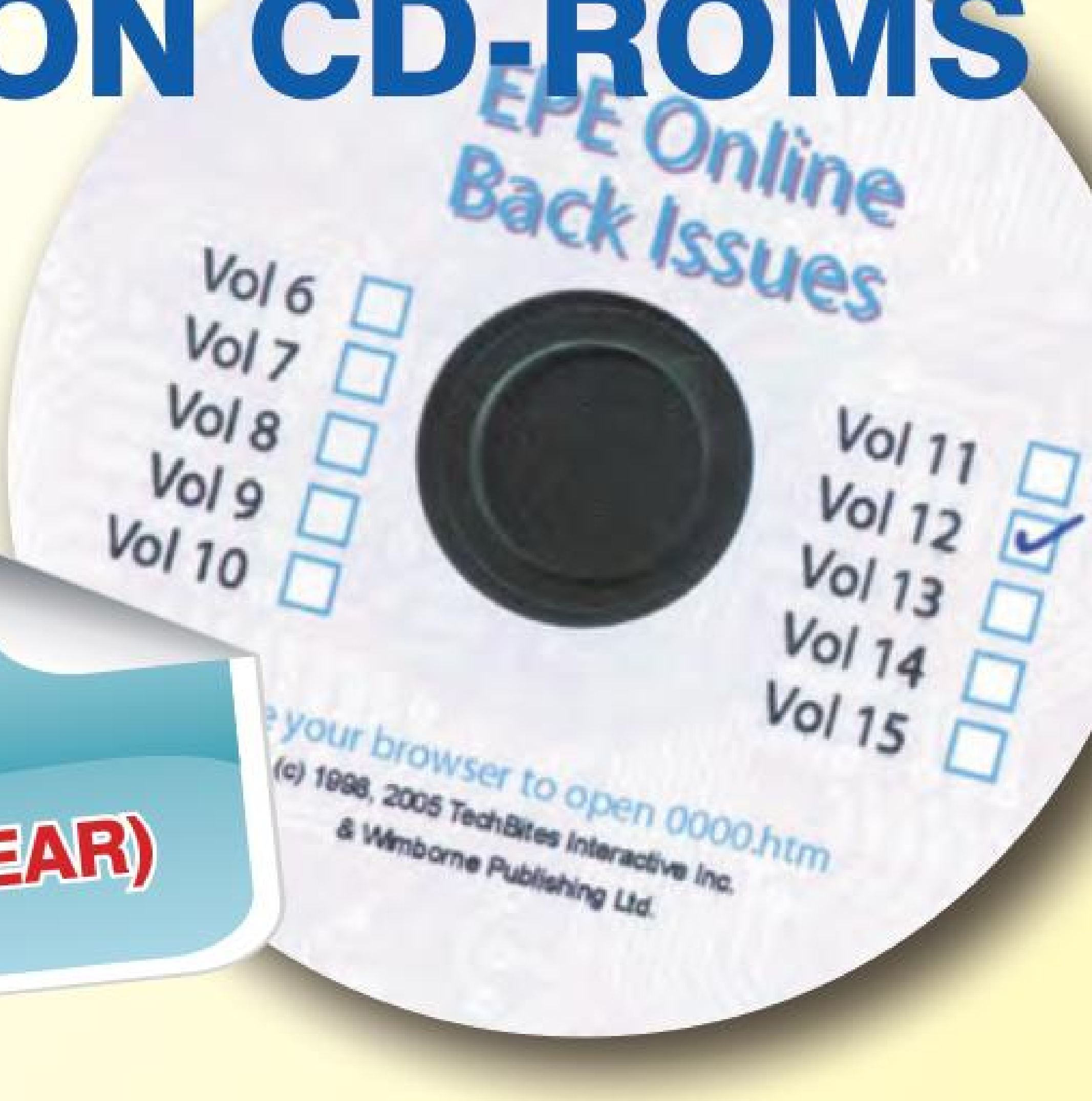

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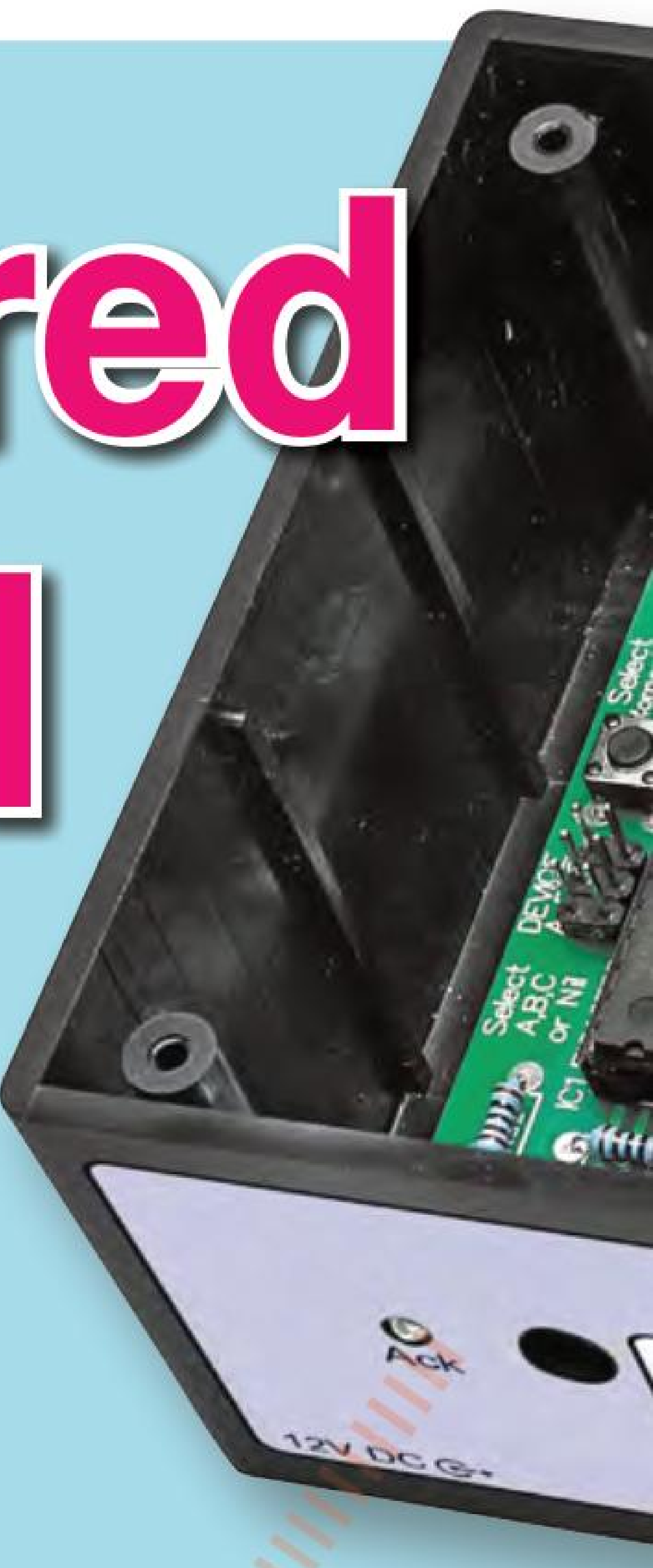
9-Channel Infrared Remote Control



Using a tiny, prebuilt 9-button remote, this infrared remote control receiver is ideal for use with TVs, Hi-Fi and audio-visual equipment, model train layouts and robot control. Not only that, but the one tiny handheld remote can be used to control up to three separate receivers, each with seven channels. No surface-mount parts are used in the design and it can run from a 12V battery or DC plugpack.

By JOHN CLARKE

INFRARED REMOTE controllers are great, but most universal remote controls tend to have lots of pushbuttons to cater for numerous functions and are quite bulky. If you only need a few functions, a much smaller remote is a lot more convenient.

That is why this project uses a tiny IR remote from Sparkfun in the US (also available via **amazon.co.uk**). Normally sold for use in Arduino projects, it's used here with a dedicated receiver which controls up to nine output channels. Alternatively, it can control three independent receivers, with up to seven outputs each. That might sound a little confusing, but the upshot is that this is a powerful control system with lots of options.

The Sparkfun IR remote measures only 80 × 40 × 7mm and is powered by a 3V lithium CR2025 button cell. It has nine snap-action pushbuttons: on/off (shown with the Power logo), A, B and C, and a 5-switch array with 'OK', up, down, left and right. The 5-button array is ideal for volume and channel selectors or forward, reverse, left and right functions (eg, in a model railway system).

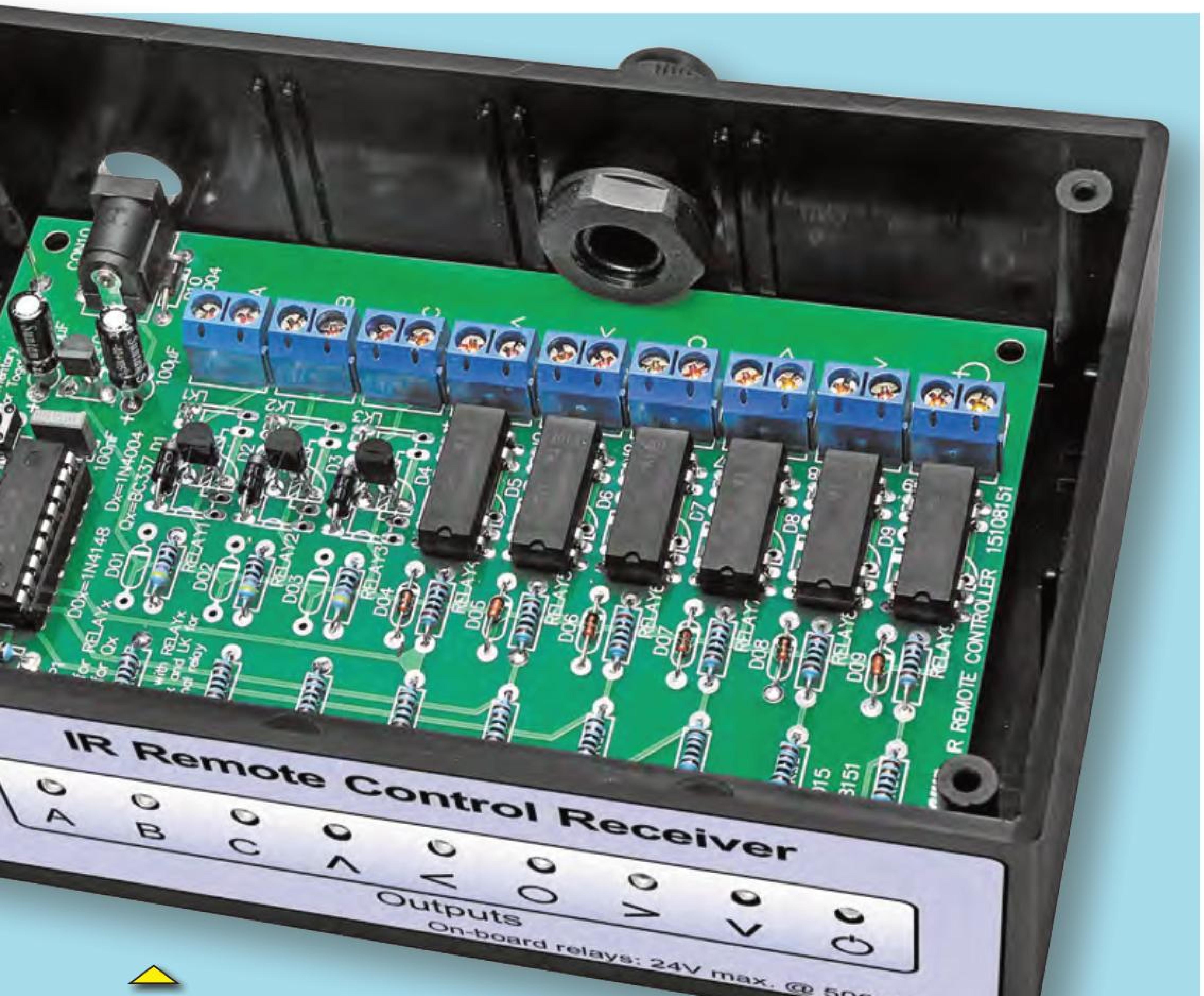
The Sparkfun remote comes fully assembled and uses a 16-pin surface-mount IC, type HB8101P. It sends a unique code via an infrared LED for each of the nine pushbuttons. The infrared signal is in 38kHz bursts, in a format known as 'Pulse Distance Protocol'. The controller has nine corresponding outputs and one of these will be switched if a valid code is received.

The nine outputs can be switched by reed relays, open-collector transistors or a combination of both. The transistor outputs can be used to directly switch LEDs or to switch relays with higher contact ratings than those of the on-board reed relays.

By the way, you don't need to build the controller with all nine outputs if you don't need them; just build it with as many as you need.

Momentary or toggle?

Each output can be set for momentary or toggle (sometimes called alternate) operation. Momentary operation is


IR Remote Control Receiver
A
B
C
^
<
O
>
V
⏻
Outputs
On-board relays: 24V max. @ 500mA
IR REMOTE CONTROLLER 15108151

The receiver can control nine output channels or can be built as an A, B or C device with seven output channels.

Features and specifications

Features

- Uses pre-built miniature 9-button hand-held remote
- Nine output channels (single receiver unit)
- Optional A, B or C device (receiver) addressing with seven channels per device
- Reed relay outputs or open-collector outputs (suitable for a 12V DC coil relay)
- LED indicators
- Momentary or toggle operation on each output

Specifications

- IR reception range: 15m
- Power: 12VDC at 150mA minimum (increase current rating for any added relay coil current)
- Output ratings: reed relay contacts or open-collector outputs, 24V @ 500mA.
- IR coding: Pulse Distance Protocol
- Reception frequency adjustment: ±12.5% in 16 steps (~1.5% steps)

where an output and its associated indicating LED is switched on only while the button for that function is being pressed. It goes off immediately when the button is released.

For toggle operation, an output is set to switch on with one press of an IR remote button and it will stay on until the same button is pressed again; a further press of the button switches the output off again.

A pushbutton switch on the controller board is used to select momentary or toggle operation for each individual output and the unit remembers this setting even if the power is switched

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Parts List

- 1 double-sided PCB available from the *EPE PCB Service*, coded 15108151, 132 × 87mm
- 1 front panel label, 148 × 45mm
- 1 9-button IR remote control, (Sparkfun COM-11759) – available direct from Sparkfun in the US, or via **amazon.co.uk** (search for Sparkfun electronics COM-11759)
- 1 CR2025 3V alkaline cell
- 1 UB1 plastic case, 158 × 95 × 53mm
- 1 SPST micro-tactile switch with 0.7mm (or similar) actuator (S1)
- 1 12V DC plugpack rated at 150mA or more (see text)
- 1 2.1mm or 2.5mm PCB-mount DC socket to suit plugpack (CON10)
- 9 2-way screw terminals, 5.08mm pitch (CON1-CON9)
- 1 cable gland to suit wiring
- 1 18-pin DIL IC socket
- 1 3-way DIL header (2.54mm spacings)
- 1 jumper shunt for header
- 3 PC stakes (TP GND, TP1, TP2)

Semiconductors

- 1 PIC16F88-I/P microcontroller programmed with 1510815B.hex (IC1)
- 1 TOSOP4838 or equivalent 38kHz IR receiver (IRRx1)
- 1 78L05 5V 100mA regulator (REG1)
- 9 high brightness 3mm red LEDs (LED1-LED9)
- 1 high brightness 3mm green LED (LED10)
- 1 1N4004 1A diode (D10)

Capacitors

- 2 100µF 16V PC electrolytic
- 1 10µF 16V PC electrolytic
- 1 100nF MKT polyester

Resistors (0.25W, 1%)

10 1kΩ 1 470Ω 1 100Ω

Reed relay outputs*

- 9 SPST DIP 5V reed relays (Altronics S4100A, Jaycar SY-4030) (Relay1-Relay9)
- 9 1N4148 diodes (D11-D19)
- 9 100Ω 0.25W, 1% resistors

Open collector outputs*

- 9 BC337 NPN transistors (Q1-Q9)
- 9 1N4004 diodes (D1-D9)
- 9 470Ω 0.25W, 1% resistors
- LK1-LK9 = resistor lead off-cuts

** Adjust part numbers required for a mix of reed relay and open collector outputs*

off. Note that all the outputs are always initially off whenever power is applied to the controller.

Three separate devices

As already noted, the Sparkfun remote can be used to select and control up to three separate devices, designated A, B and C. But if you want three separate devices, you need three separate receivers. So to select one of the three devices, you press button A, B or C on the remote and then the remaining buttons on the remote can be pressed to control the various functions on the selected receiver.

The receiver incorporates three jumper positions that allow it to be set as an A, B or C device.

Alternatively, if you don't need to control multiple receiver units, you simply leave out the jumper. In this mode, all nine outputs in the receiver unit are active and can be controlled by the remote.

Circuit details

Now have a look at Fig.1, which shows the circuit details of the controller. It employs an infrared receiver/decoder (IRRx1) and a PIC16F88-I/P microcontroller (IC1) which directly drives reed relays, NPN transistors or a combination of both, depending on how you configure the PCB.

IRRx1 is a 3-lead device that comprises an infrared detector, amplifier, 38kHz bandpass filter and automatic gain control (AGC). Normally, IRRx1's output is high (5V) and it goes low when it receives a 38kHz IR signal. The supply for IRRx1 is derived via a 100Ω resistor from the 5V rail and is decoupled by a 100µF electrolytic capacitor.

IRRx1's output connects to the RB0 input of IC1. IC1 in turn decodes the 38kHz signal to drive the outputs according to the infrared code sent by the handheld remote. Each output comprises an indicator LED driven via a 1kΩ resistor and either a 100Ω resistor which drives a reed relay or a 470Ω resistor which drives the base of an NPN transistor.

Note that wherever a reed relay is used, a reverse-biased diode (D11-D19) is used to clamp any transient voltage from the relay's coil when it is switched off.

By contrast, if a transistor is used instead, a diode (D1-D9) is used to clamp any transients from an external relay. Whenever the transistor is turned on, the external relay is enabled (turned on). Note that the circuit shows one output driven from RB1 (pin 7) and one driven by RA1 (pin 18) but seven other outputs are also available, depending on whether you install the relevant components on the PCB.

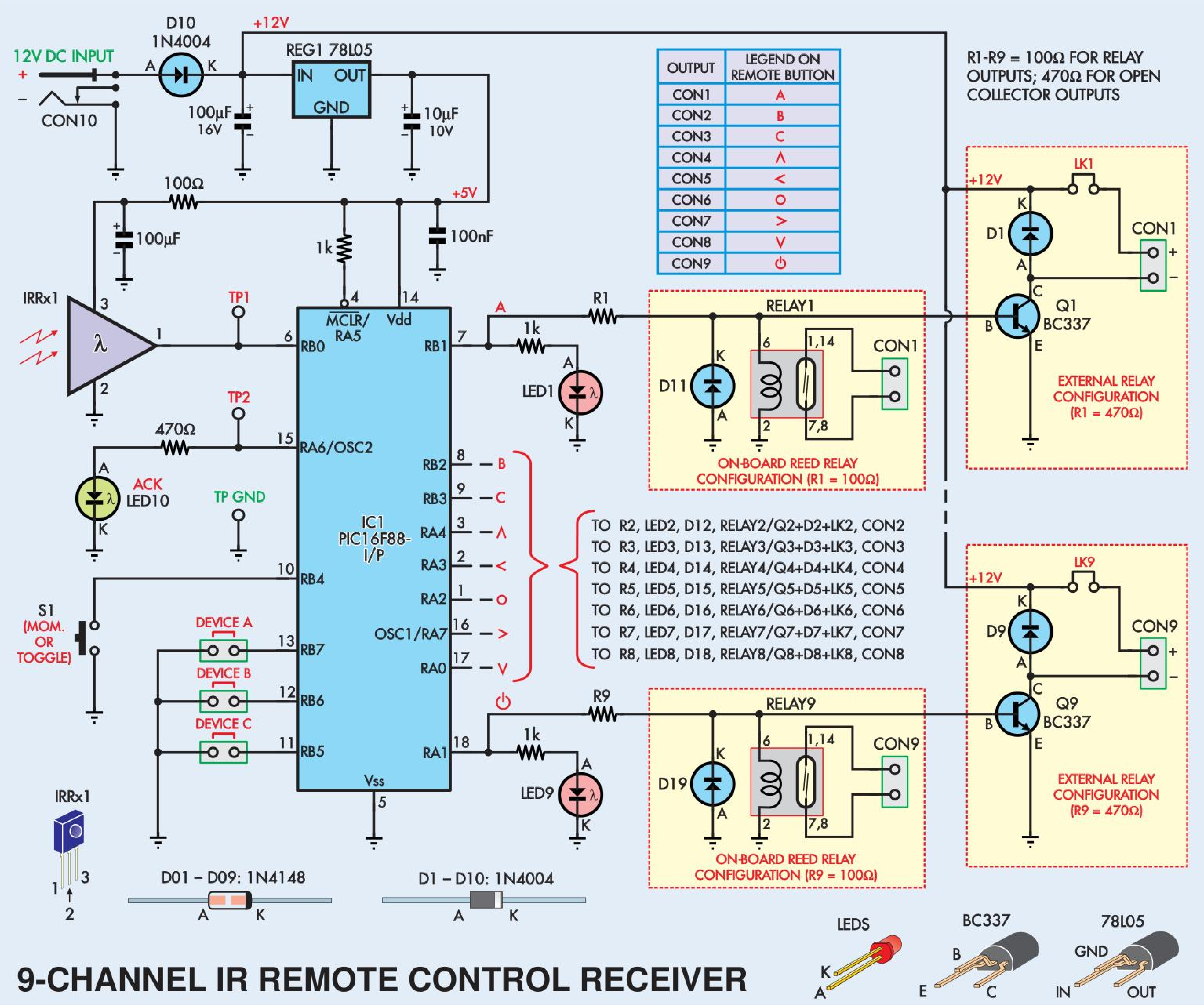
The acknowledge LED (LED10) is driven via IC1's RA6 output and flashes whenever an infrared signal is received. It's turned on when a signal from IRRx1 is detected by IC1 as a low and is off when IRRx1's output is high.

In addition, LED10 does double-duty as a power indicator. When power is applied, it briefly flashes every second (ie, at a 1Hz rate) but flashes rapidly if an IR signal is received by IRRx1.

The RB4, RB5, RB6 and RB7 inputs are normally high (+5V) unless pulled to 0V via momentary pushbutton switch S1 (for RB4) or the link options for the A, B or C inputs at RB7, RB6 and RB5. Only one jumper shunt should be used if the controller is to be used in its device mode (ie, with A, B or C). If more than one jumper is connected, say A and B, only A will be recognised.

Note that if the Device A jumper is installed, then outputs B and C are disabled while the others all function normally. However, pressing either button B or C on the remote will always turn the A output off (if it's on), while the other outputs will be left in their current state. These outputs will then not respond to further button presses on the remote unless the Device A button on the remote is pressed again.

The Device B and Device C jumper options work in similar fashion, ie, a Device B jumper selection disables the receiver's A and C outputs, while a Device C jumper selection disables the A and B outputs.


12V DC INPUT
CON10
D10
1N4004
+12V
REG1 78L05
IN OUT GND
100µF 16V
10µF 10V
100Ω
+5V
100µF
1k
100nF
IRRx1
TP1
TP2
TP GND
470Ω
ACK LED10
S1 (MOM. OR TOGGLE)
DEVICE A
DEVICE B
DEVICE C
MCLR/RA5
Vdd
RB0
RB1
RA6/OSC2
RB2
RB3
RA4
RA3
RA2
OSC1/RA7
RA0
RB4
RB7
RB6
RB5
RA1
Vss
IC1 PIC16F88-I/P
R1
R9
LED1
LED9
D11
D19
RELAY1
RELAY9
CON1
CON9
ON-BOARD REED RELAY CONFIGURATION (R1 = 100Ω)
ON-BOARD REED RELAY CONFIGURATION (R9 = 100Ω)
OUTPUT | LEGEND ON REMOTE BUTTON
CON1 | A
CON2 | B
CON3 | C
CON4 | ʌ
CON5 | <
CON6 | o
CON7 | >
CON8 | v
CON9 | ⏻
R1-R9 = 100Ω FOR RELAY OUTPUTS; 470Ω FOR OPEN COLLECTOR OUTPUTS
LK1
LK9
D1
D9
Q1 BC337
Q9 BC337
EXTERNAL RELAY CONFIGURATION (R1 = 470Ω)
EXTERNAL RELAY CONFIGURATION (R9 = 470Ω)
TO R2, LED2, D12, RELAY2/Q2+D2+LK2, CON2
TO R3, LED3, D13, RELAY3/Q3+D3+LK3, CON3
TO R4, LED4, D14, RELAY4/Q4+D4+LK4, CON4
TO R5, LED5, D15, RELAY5/Q5+D5+LK5, CON5
TO R6, LED6, D16, RELAY6/Q6+D6+LK6, CON6
TO R7, LED7, D17, RELAY7/Q7+D7+LK7, CON7
TO R8, LED8, D18, RELAY8/Q8+D8+LK8, CON8
D01 – D09: 1N4148
D1 – D10: 1N4004
LEDS
BC337
78L05
GND
IN OUT
B E C
K A

9-CHANNEL IR REMOTE CONTROL RECEIVER

Fig.1: the circuit is based on infrared receiver/decoder (IRRx1) and a PIC16F88-I/P microcontroller (IC1). IC1 decodes the signal from IRRx1 and its outputs drive either reed relays (Relays1-9) or open-collector transistors (Q1-Q9). LEDs1-9 provide channel on/off indication, while the jumpers at IC1's RB5-RB7 inputs provide optional device selection.

If no device jumper is fitted, then no channels are disabled and the remote controls all of the receiver's outputs.

Frequency adjustment

While the handheld remote and the controller are designed to operate with Pulse Distance Protocol, the actual times for each 38kHz burst and the off times can vary from specification. This is due to tolerances in the clocking rate for the code transmission and in measuring the transmission time periods. That's because the transmitter and controller ICs run using internal oscillators that are not precise.

We have dealt with that by arranging for the microcontroller's software to cater for up to a 10% variation in frequency for the transmission rate and the detected time period. However, in some cases this may not be sufficient to reliably detect and decode transmissions. If that is the case, the software controller allows IC1's internal oscillator to be shifted in frequency. The available range of correction is ±12.5%, with adjustment steps in either direction of about 1.5%.

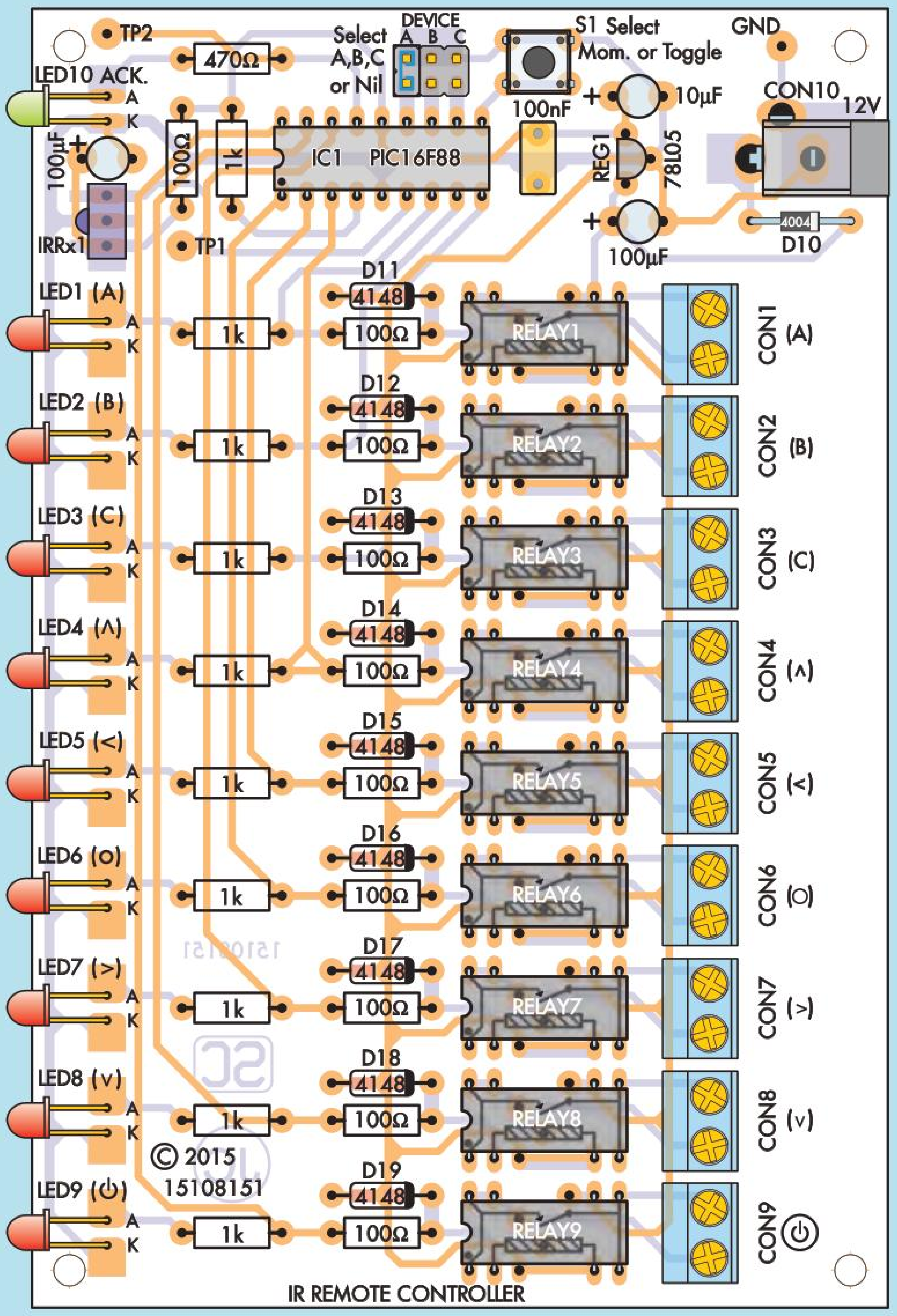
All of the relays and/or transistor outputs are powered from the +12V rail which is fed via reverse-polarity protection diode D10. The 5V supply for IRRx1 and IC1 comes from REG1, a 78L05 regulator. Its input and output are bypassed with 100µF and 10µF capacitors, respectively. In addition, IC1's supply is bypassed with a 100nF capacitor close to the supply pins.

Construction

Building the *Remote Control Receiver* is easy, with all parts installed on a PCB coded 15108151 (132 × 87mm) which is available from the *EPE PCB Service*. This is housed in a UB1 plastic case measuring 158 × 95 × 53mm; a 148 × 45mm panel label is affixed to the side.

Figs.2 and 3 show the parts layouts for two different versions. Follow Fig.2 to build the unit with reed relay outputs or Fig.3 if you want open collector transistor outputs (eg, to switch external relays).

Alternatively, you can have a mix of relay and open-collector outputs. It's


TP2
470Ω
LED10 ACK.
A
K
Select A,B,C or Nil
DEVICE A B C
S1 Select Mom. or Toggle
GND
100nF
10µF
CON10
12V
100µF
100Ω
1k
IC1 PIC16F88
REG1
78L05
IRRx1
TP1
100µF
4004
D10
D11 4148 ... D19 4148
LED1 (A)
LED2 (B)
LED3 (C)
LED4 (∧)
LED5 (<)
LED6 (O)
LED7 (>)
LED8 (∨)
LED9 (⏻)
1k
100Ω
RELAY1
RELAY2
RELAY3
RELAY4
RELAY5
RELAY6
RELAY7
RELAY8
RELAY9
CON1 (A)
CON2 (B)
CON3 (C)
CON4 (∧)
CON5 (<)
CON6 (O)
CON7 (>)
CON8 (∨)
CON9 ⏻
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IR REMOTE CONTROLLER

ALL CHANNELS CONFIGURED WITH ON-BOARD RELAYS

Fig.2: follow this PCB layout to build the unit with reed relay outputs. A jumper is shown here in the Device A position, but this should be omitted if you only want a single 9-channel receiver.

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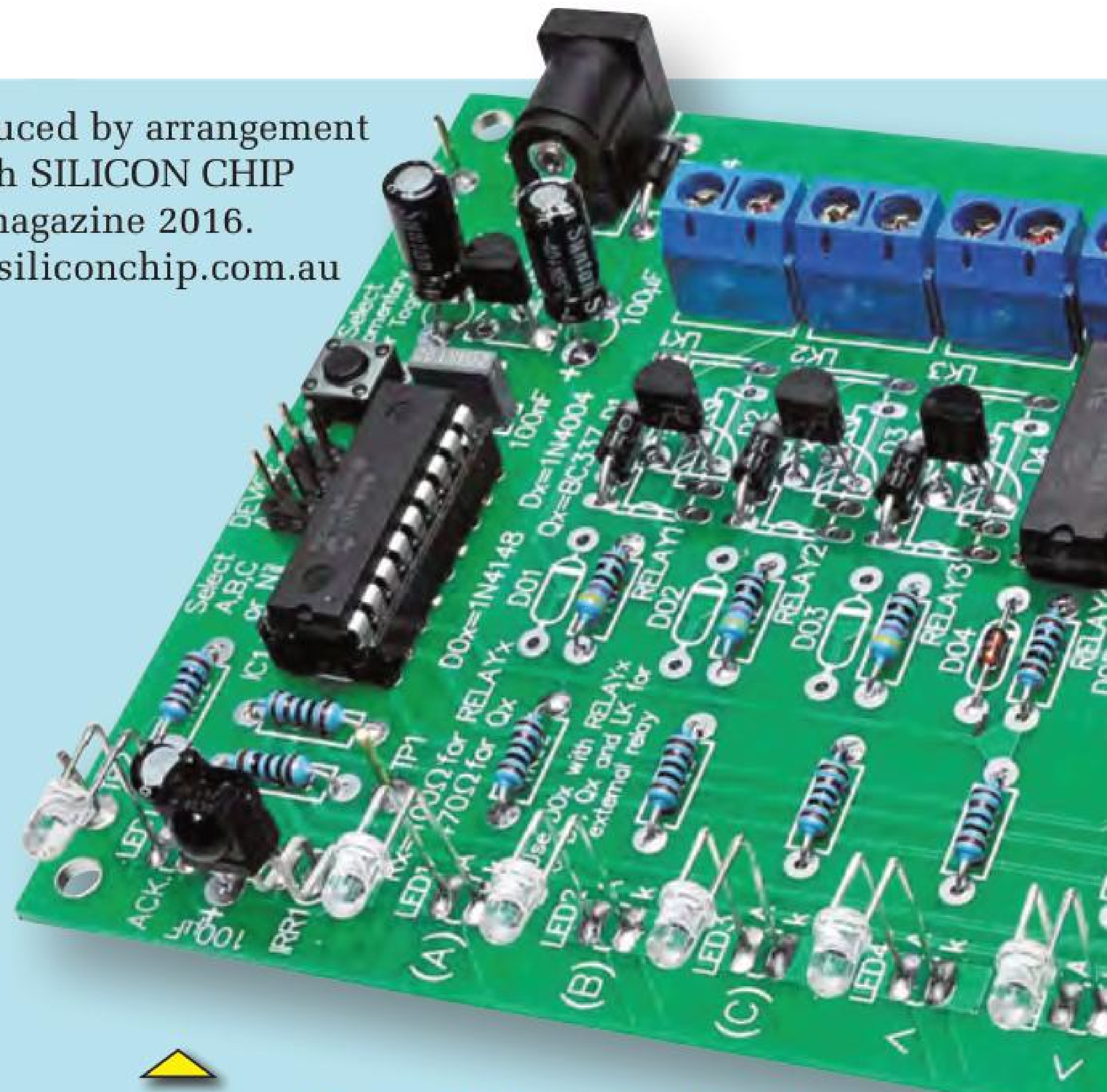


Our prototype PCB was built with open-collector transistors for outputs A, B and C and reed relays for the remaining six outputs.

just a matter of referring to either Fig.2 or Fig.3 and installing the appropriate output components for that channel.

As shown in the photos, our prototype was built with open-collector transistors for outputs A, B and C and reed relays for the remaining six outputs. Note that the output channel symbols match the buttons on the remote control.

Note also that if you plan to set the controller for device operation, you don't need to fit the output components for the disabled channels. For example, if the controller is to be an A device, then the B and C output components (including LEDs 2 and 3) do not need to be installed.

Similarly, you can leave out the output components for any other channel that isn't required, but note that LED1 is required for Device A operation since this is the Device A indicator. Alternatively, you will need to install LED2 for Device B operation or LED3 for Device C operation.

If sorting that out all sounds too hard, then you can just install all the parts for each output channel.

Begin the assembly by fitting the resistors. Table 1 shows the resistor colour codes, but you should also check their values using a DMM before soldering them to the PCB.

Be sure to fit the correct values for resistors R1-R9. 100Ω resistors must be installed for the reed relay channels, while 470Ω resistors are used with the open-collector transistors.

The diodes go in next. Note that D11-D19 on Fig.2 are 1N4148 types, while D1-D9 on Fig.3 are 1N4004s and occupy different positions. D10 is a 1N4004 on both versions. Take care to ensure that the diodes are all oriented correctly.

Next, fit the PC stakes for TP1, TP2 and TP GND, then install an 18-pin DIL socket for IC1 (notched end to the left). The capacitors can then be soldered in place, taking care to ensure that the three electrolytics are

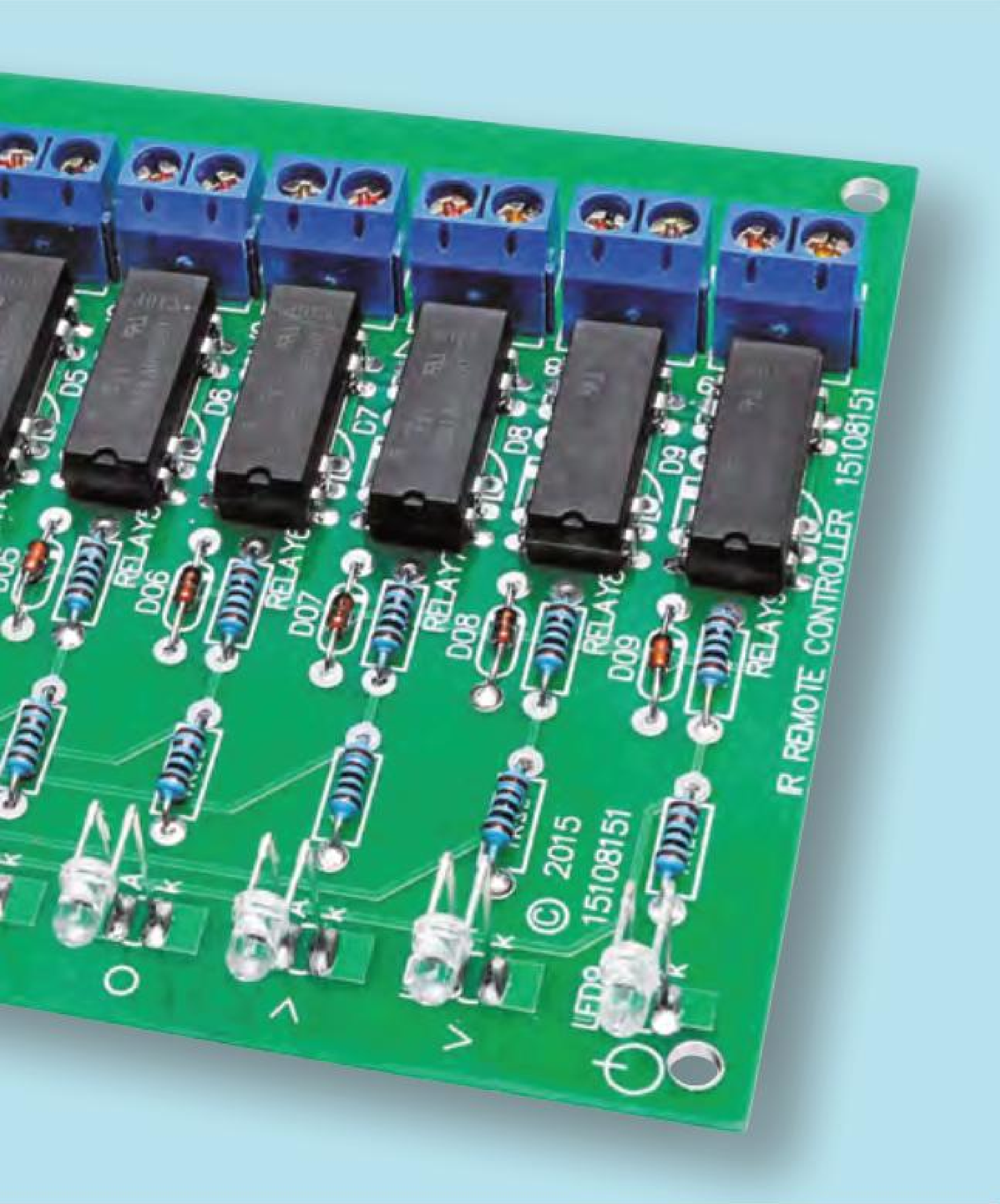
Front panel labels

The front-panel label is optional. It can be made by downloading the relevant PDF file from the *EPE* website and then printing it out as a mirror image onto clear overhead projector film (use film that's suitable for your printer). By printing a mirror image, the toner or ink will be on the back of the film when it's fitted. The label can be secured in place using white or grey silicone adhesive.

Alternatively, print onto a synthetic Dataflex sticky label with an inkjet printer or a Datapol sticky label with a laser.

(1) For Dataflex labels, go to: **www.blanklabels.com.au/index.php?main_page=product_info&cPath=49_60&products_id=335**

(2) For Datapol labels go to: **www.blanklabels.com.au/index.php?main_page=product_info&cPath=49_55&products_id=326**


IR REMOTE CONTROLLER 15108151
© 2015 15108151

oriented correctly. The 100nF polyester (MKT) capacitor can be fitted either way around.

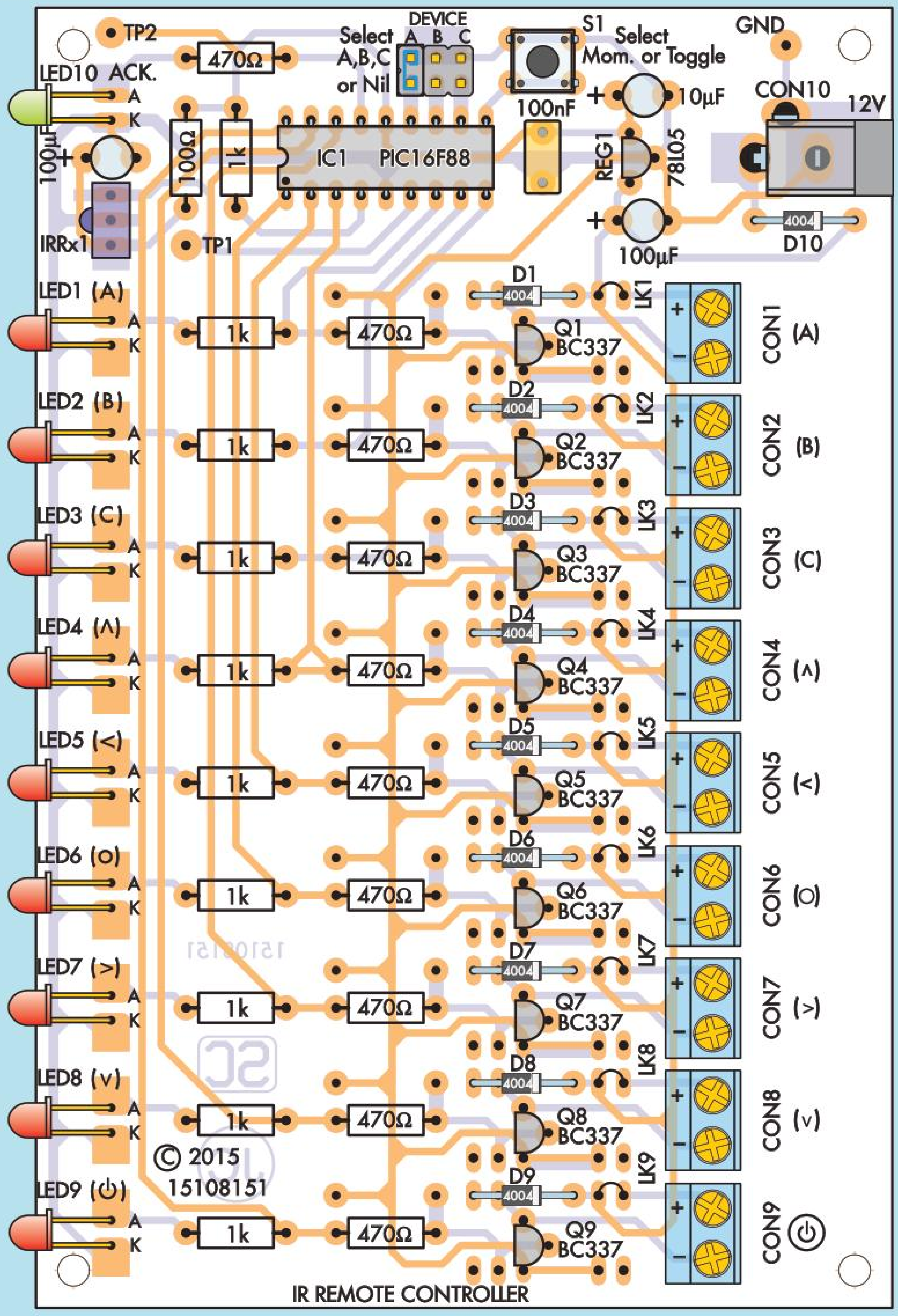
Follow with the DC socket and switch S1, then install transistors Q1-Q9 (as required) and regulator REG1. Links LK1-LK9 can now be installed in those channels where a transistor is fitted. These links are only very short (less than 5mm) and can be fashioned using resistor lead off-cuts.

The 3-way DIL header for device selection is installed near IC1. Its short pin lengths go into the PCB, while the longer pin lengths on top accommodate the jumper shunt (if fitted).

Screw-terminal blocks CON1-CON9 can now all be installed. Make sure that they sit flush against the PCB and that their wire entry holes are to the right before soldering their pins.

LEDs and infrared detector

Fig.4 shows how the LEDs are installed. As shown, their leads must be bent down by 90° exactly 6mm from their bodies and that's best done using a 6mm-wide cardboard template. **Make sure that each LED's cathode (K)**


TP2
470Ω
Select A,B,C or Nil
DEVICE A B C
S1 Select Mom. or Toggle
GND
LED10 ACK.
A
K
100nF
10µF
CON10
12V
100µF
100Ω
1k
IC1 PIC16F88
REG1
78L05
IRRx1
TP1
100µF
4004
D10
LED1 (A)
LED2 (B)
LED3 (C)
LED4 (^)
LED5 (<)
LED6 (O)
LED7 (>)
LED8 (v)
LED9 (⏻)
1k
470Ω
D1
D2
D3
D4
D5
D6
D7
D8
D9
4004
Q1 BC337
Q2 BC337
Q3 BC337
Q4 BC337
Q5 BC337
Q6 BC337
Q7 BC337
Q8 BC337
Q9 BC337
LK1
LK2
LK3
LK4
LK5
LK6
LK7
LK8
LK9
+
–
CON1 (A)
CON2 (B)
CON3 (C)
CON4 (^)
CON5 (<)
CON6 (O)
CON7 (>)
CON8 (v)
CON9 (⏻)
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IR REMOTE CONTROLLER

ALL CHANNELS CONFIGURED WITH OPEN COLLECTOR OUTPUTS

Fig.3: here's how to build the unit with open-collector transistor outputs. You can have a mixture of outputs on the same board if you wish – just configure each channel according to the relevant PCB layout diagram.

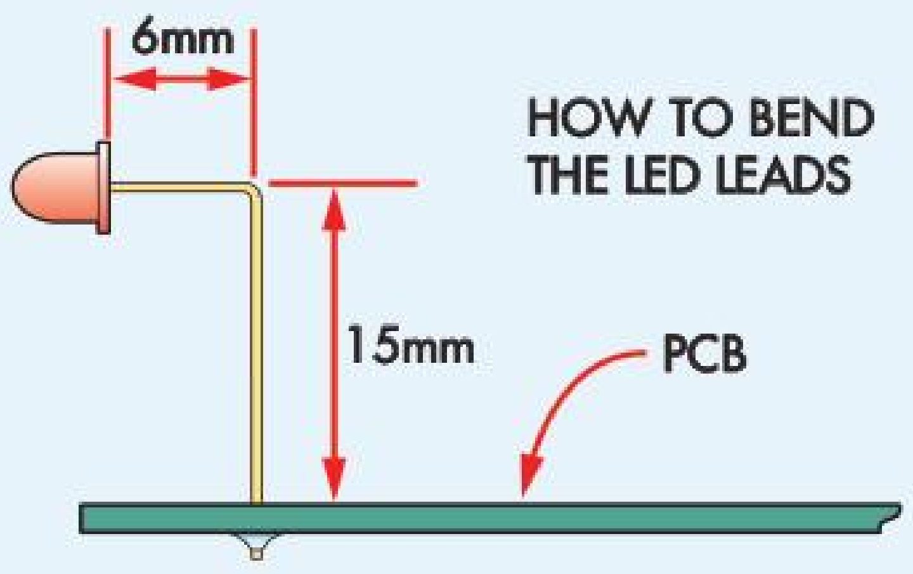

6mm
HOW TO BEND THE LED LEADS
15mm
PCB

Fig.4: each LED has its leads bent down through 90° exactly 6mm from its body before installation on the PCB. That's best done using a 6mm-wide cardboard template. Note that the LEDs are soldered to the PCB only after the latter has been installed in the case (see text).

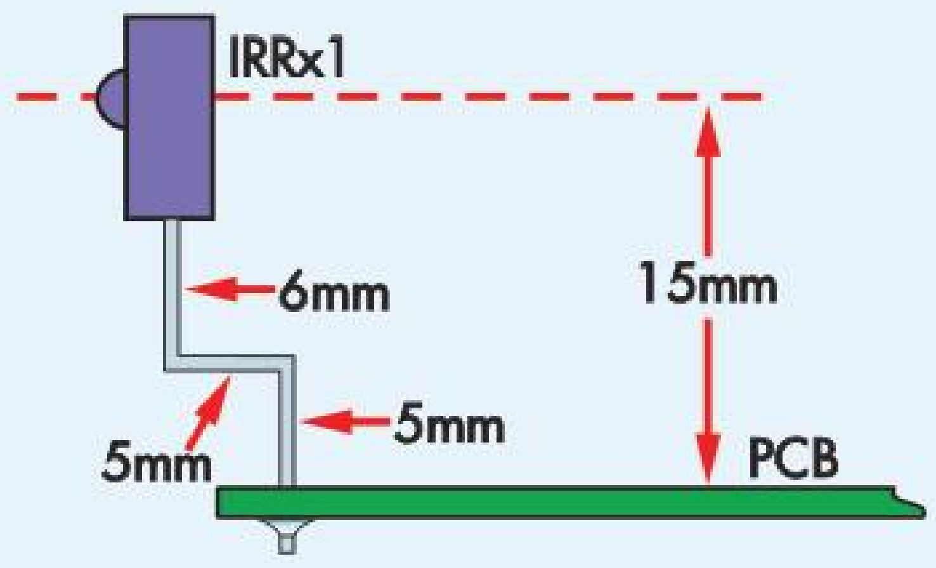

IRRx1
6mm
15mm
5mm
5mm
PCB

Fig.5: the diagram shows how to bend the leads of infrared receiver IRRx1. Bend the leads around 5mm and 6mm-wide cardboard templates and make sure that the centre of the lens is 15mm above surface of the PCB when soldering the device in place.

Table 1: Resistor Colour Codes

☐	No.	Value	4-Band Code (1%)	5-Band Code (1%)
☐	10	1kΩ	brown black red brown	brown black black brown brown
☐	1	470Ω	yellow violet brown brown	yellow violet black black brown
☐	1	100Ω	brown black brown brown	brown black black black brown

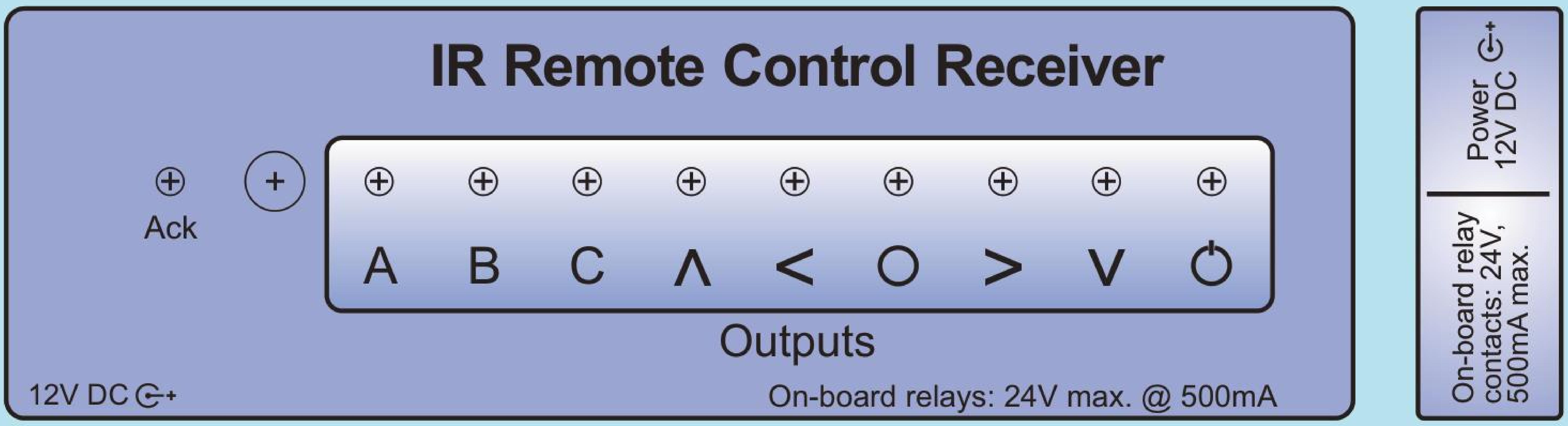

IR Remote Control Receiver
Ack
A
B
C
∧
<
○
>
∨
⏻
Outputs
12V DC
On-board relays: 24V max. @ 500mA
Power
12V DC
On-board relay
contacts: 24V,
500mA max.

Fig.6(a): use this front-panel artwork if you are building a single unit to control nine output channels. It can either be copied or downloaded in PDF format from the *EPE* website and printed onto clear film or a sticky label (see text). The rear panel artwork is shown to the right.

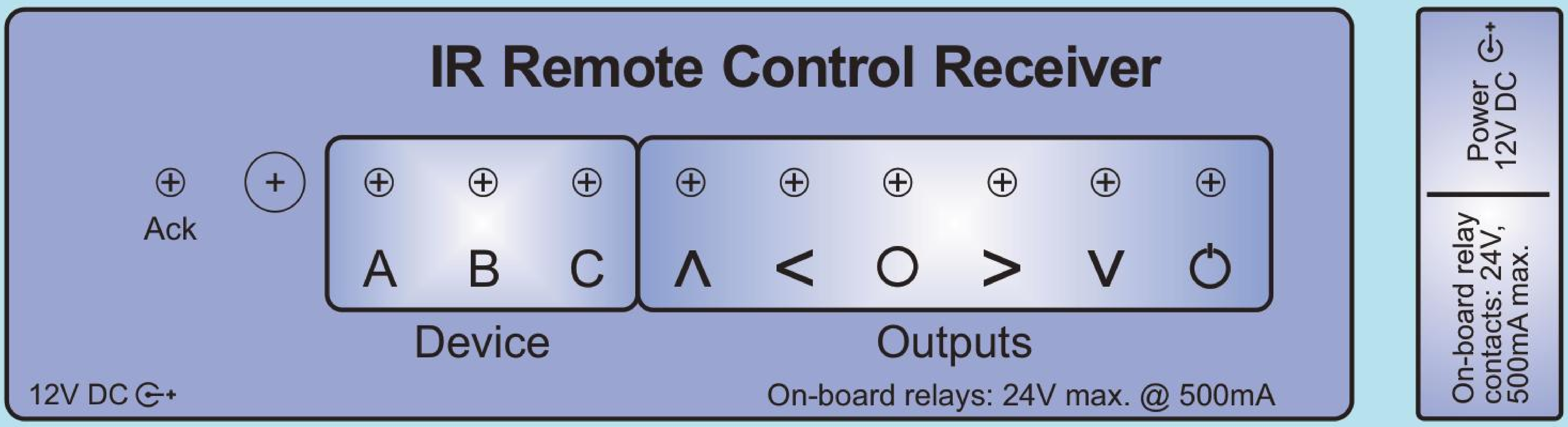

IR Remote Control Receiver
Ack
A
B
C
Device
∧
<
○
>
∨
⏻
Outputs
12V DC
On-board relays: 24V max. @ 500mA
Power
12V DC
On-board relay
contacts: 24V,
500mA max.

Fig.6(b): use these artworks if you are building more that one receiver and will be using device selection. Note that either of the above two front-panel artworks can be used as a drilling template for the case.

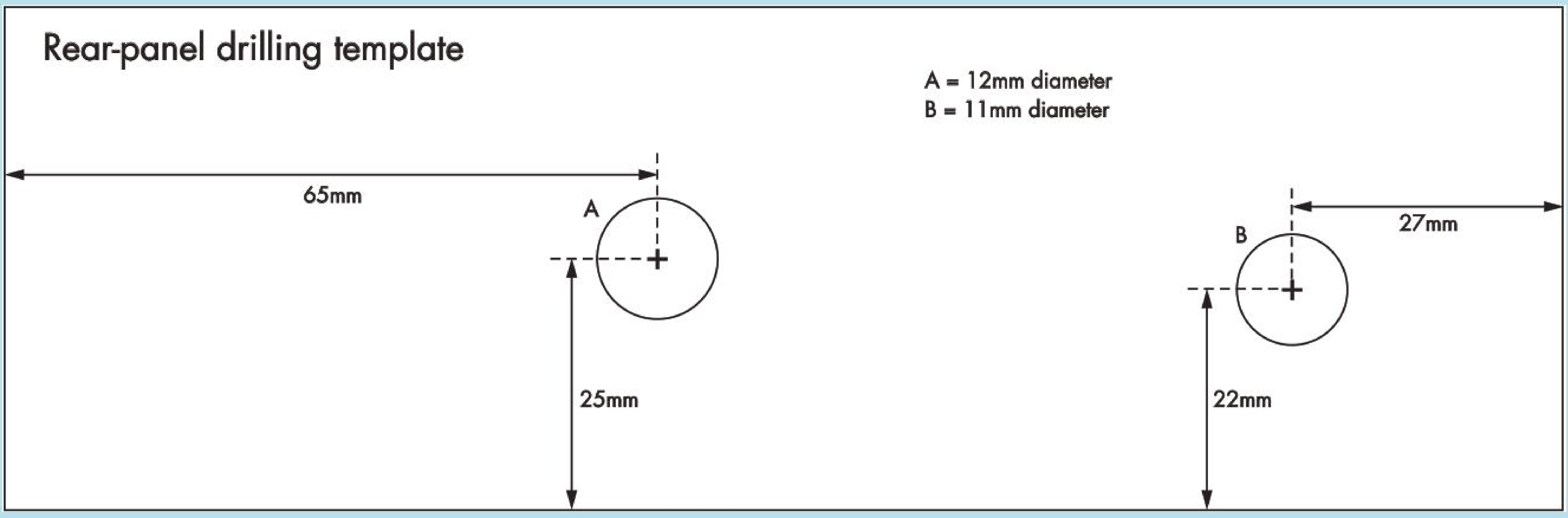

Rear-panel drilling template
A = 12mm diameter
B = 11mm diameter
65mm
A
25mm
B
27mm
22mm

Fig.7: this is the rear-panel drilling template. The two holes are best made by first drilling small pilot holes and then carefully enlarging them to size using a tapered reamer.

lead (the shorter of the two) is facing towards you before bending its leads down, so that the LEDs go in with the correct polarity.

Don't solder the LEDs to the PCB at this stage though – that step comes later, after the PCB has been installed in the case.

Having prepared the LEDs, you can now bend the infrared detector's leads as shown in Fig.5. Again, that's best done using cardboard templates, one 6mm wide and the other 5mm wide. Use the 6mm template to first bend the leads back by 90°, then use the 5mm template to bend them back down again.

Having bent IRRx1's leads to shape, solder it in place with the centre of its lens exactly 15mm above the PCB. Fig.5 shows the details.

Drilling the case

The assembled PCB (minus the LEDs) can now be put aside while you drill the UB1 plastic case. Figs.6(a) and (b) show the alternative front panels for the receiver and you can make a photocopy and use either one as a drilling template. Alternatively, you can download the labels as a single PDF file from the *EPE* website and print them out.

You need to drill 3mm-diameter holes for the 10 LEDs and a 6mm hole for infrared receiver IRRx1. Deburr all holes using an oversize drill, then drill two holes in the rear panel using the template shown in Fig.7 – one to provide access to the DC socket and the other to mount a cable gland.

The DC socket hole has a diameter of 11mm, while the cable gland hole is

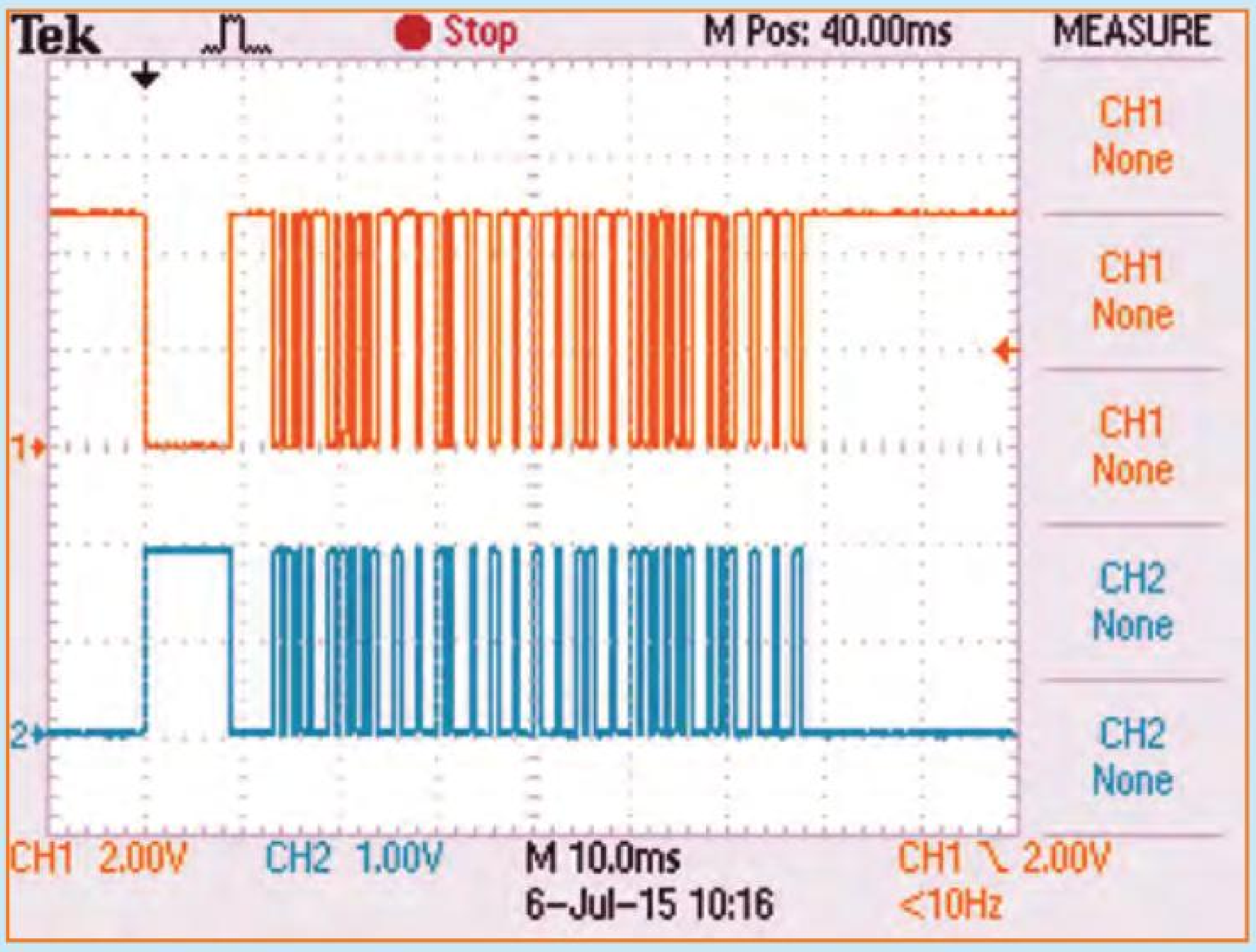
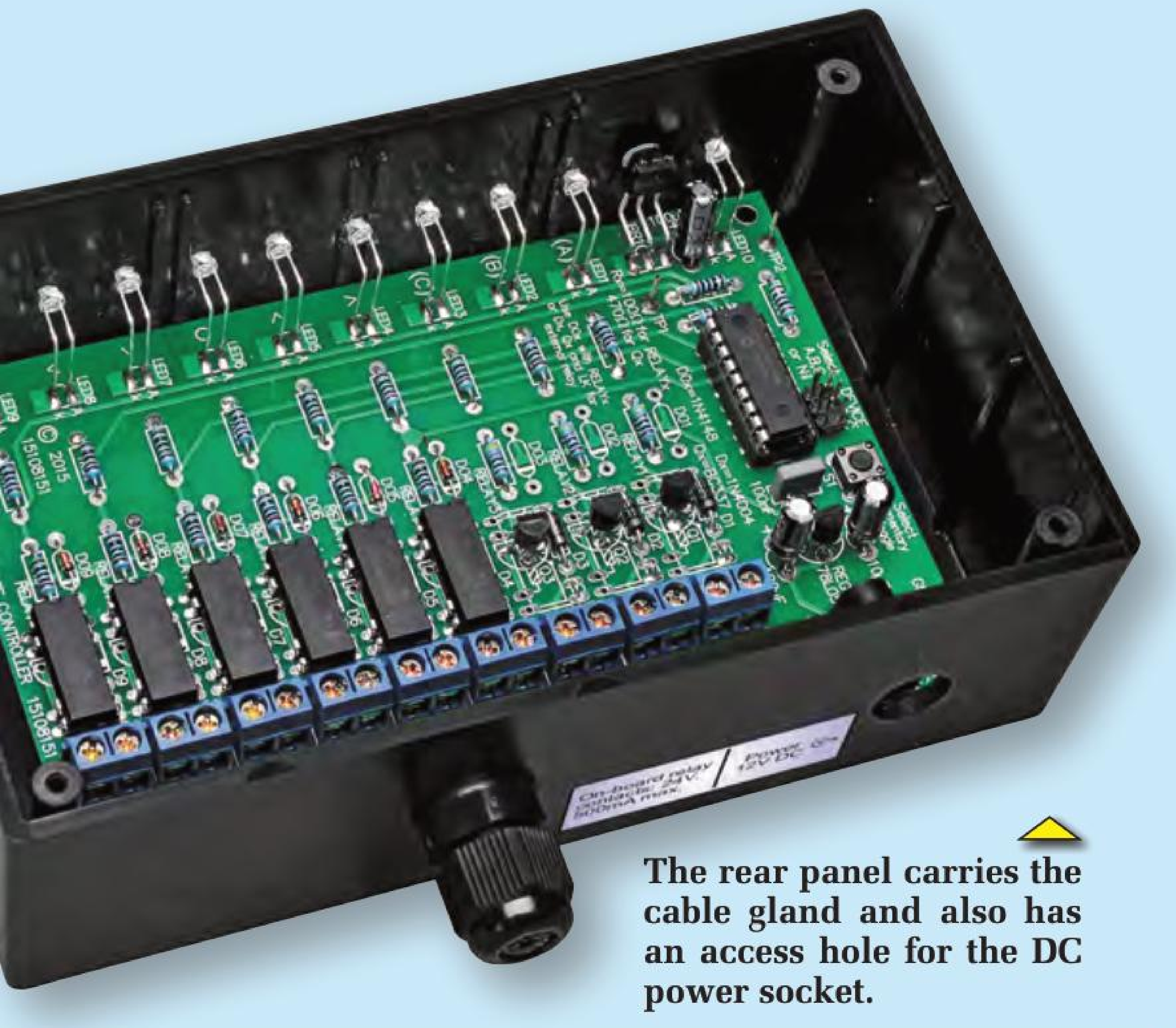


Fig.8: the top trace of this scope grab shows the output from IR detector IRRx1, while the lower trace is the Acknowledge LED voltage and shows the processed and decoded signal from the microcontroller. The initial 9ms pulse and 4.5ms gap indicate the start of the sequence (note: the coding shown is for the remote's power button).



The rear panel carries the cable gland and also has an access hole for the DC power socket.

12mm in diameter. They are best made using a small pilot drill to begin with and then carefully enlarged to size using a tapered reamer.

Now take a look inside the case. You will find that one of the LED holes goes through one of the internal plastic ribs, while another hole will be immediately adjacent to one of these ribs. **You will need to cut away the ribs from around these holes using sharp side cutters, so that the LEDs will later fit correctly.**

Final assembly

Once all the holes have been drilled, the PCB can be slid into the case and clipped into the slots using the integral side ribs. Check that the PCB is the right way around –

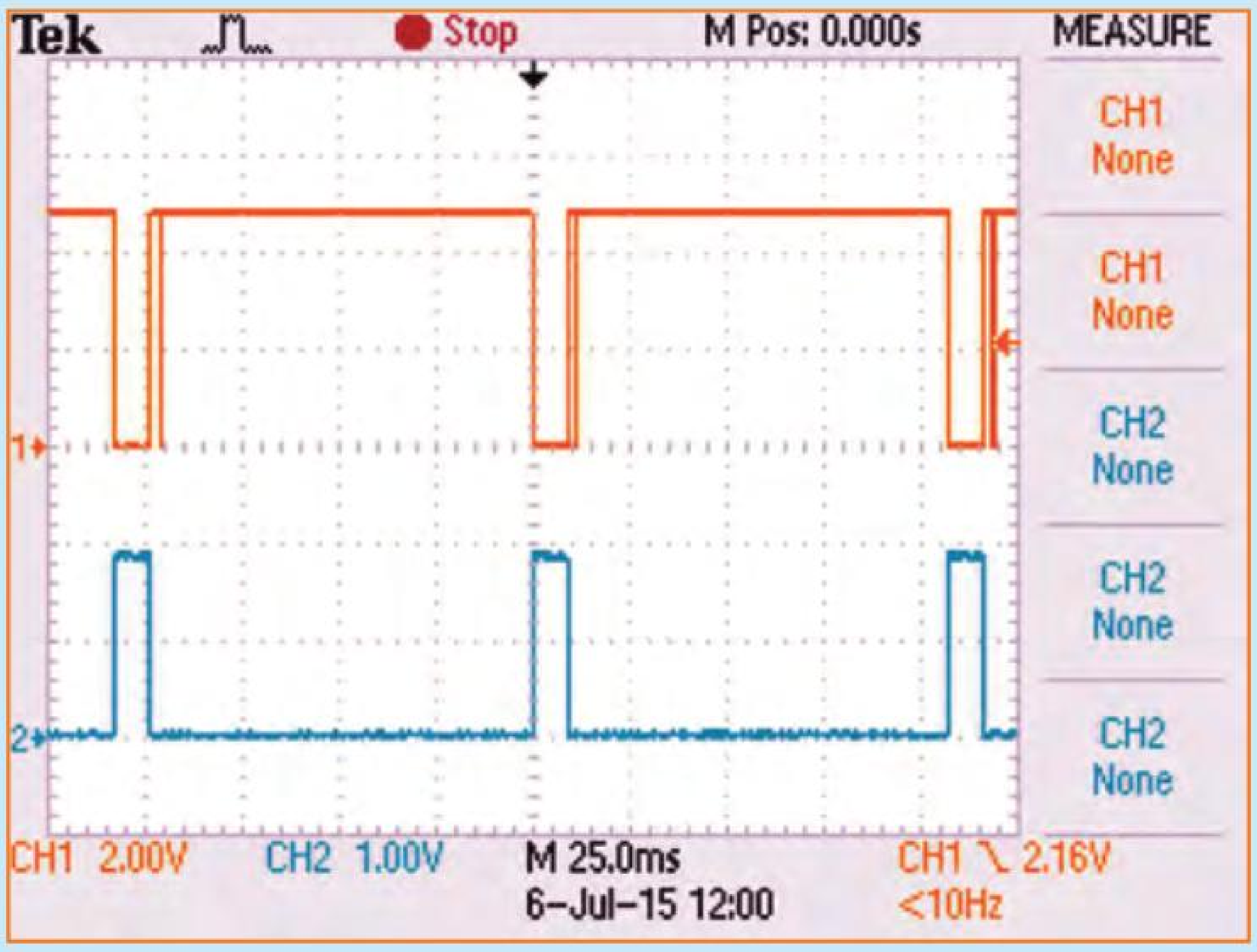


Fig.9: this scope grab shows the button repeat signal pulses. The top trace is IRRx1's output, the lower trace is the Acknowledge LED's decoded output.

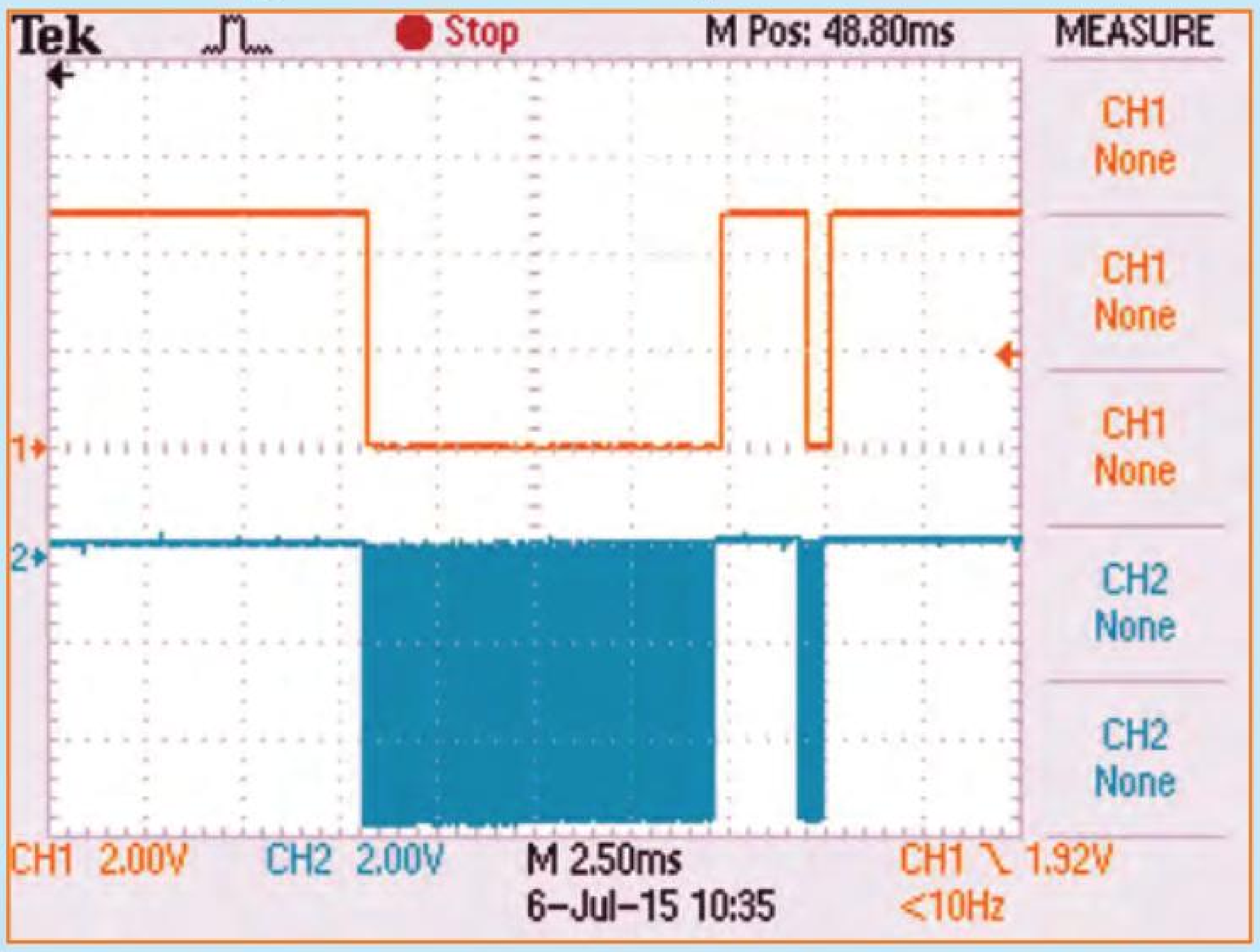


Fig.9: the bottom trace here shows the bursts of 38kHz signal, as sent by the remote's IR LED, while the top trace is the demodulated output from IRRx1. Note that IRRx1's output is low when the 38kHz IR signal is present.

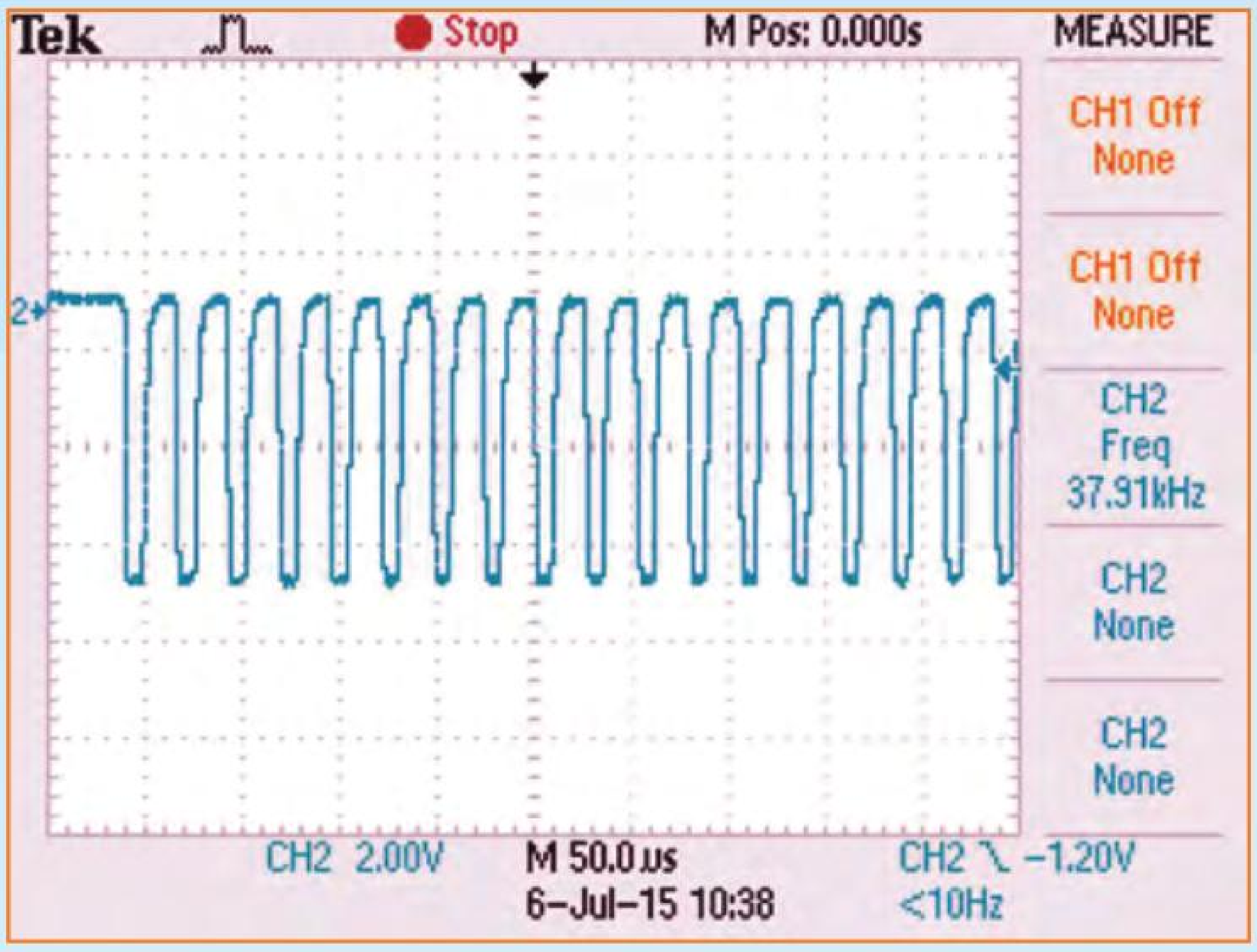


Fig.10: this shows an expanded view of the IR signal's 38kHz carrier frequency. The carrier is sent as a series of on and off pulses; ie, it's switched on and off with a particular pattern to identify a particular button.

IR Remote Control Receiver
Ack
A
B
C
∧
<
O
>
V
⏻
Outputs
On-board relays: 24V max. @ 500mA
12V DC

This view shows the completed remote control receiver. It's powered using a 12V DC plugpack rated at 150mA or more.

Compensating for frequency tolerances

Normally, you will not need to compensate for transmission rate tolerances. However, if the receiver fails to operate reliably, you will need to adjust IC1's clock rate. The procedure is as follows:

(1) Switch off power to receiver, then reapply power while holding S1 down.

(2) Continue holding S1 down; LED5 (centre LED in the row on nine) will light to indicate current oscillator setting (this is the default 'zero change' setting).

(3) Release S1; LED5 will turn off and the Acknowledge LED (LED10) will turn on to indicate that the receiver is now in the oscillator adjustment mode (it can still flash if it receives a signal from the remote).

(4) Press switch S1 again. LED 5 and LED6 will now both light to indicate that IC1's oscillator frequency has been slowed.

(5) Release S1 and test the receiver using the remote to see if it now operates reliably. If not, press S1 again; LED6 will now be lit on its own, indicating a further slowing of the oscillator frequency. Check the unit once again to see if it now operates reliably.

(6) Pressing S1 again will now light LED6 and LED7, then LED7 on its own, then LED7 and LED8 and so on up to LED9, with each step progressively slowing IC1's oscillator. Check for reliable operation after each step.

(7) Pressing S1 after LED9 has been lit moves display back to the left (ie, towards LED1). When LED5 is reached, pressing S1 again will light LED5 and LED4. This indicates that the frequency has been increased by one step from the default value. Further presses of S1 then light LED4, then LED4 and LED3, then LED3 on its own, then LED3 and LED2 and so on, with each step increasing the frequency.

(8) Once you've found a setting that gives reliable operation, switch off and then reapply power to get out of the frequency-adjustment mode. The Acknowledge LED should now resume normal operation (ie, it will flash briefly at a 1Hz rate to indicate that power is applied, or flash rapidly if a signal is received from the remote).

the pads for the LEDs must be adjacent to LED holes in the side of the case.

The 10 LEDs can now be fitted in place and their leads soldered to their pads on the top of the PCB. Check that each LED is correctly oriented and that it protrudes through its front-panel hole before soldering its leads. LEDs1-9 are all red LEDs while LED10 (Power/Acknowledge) is green.

Now check that the infrared detector's lens is correctly aligned with its front-panel hole. If not, bend its leads until it's centred.

Testing

Now for the smoke test. Apply power using a 12V DC plugpack and check that the voltage between pins 14 and 5 of IC1's socket is close to 5V (4.85-5.15V). If no voltage is present, check diode D10's polarity and check the polarity of the plugpack supply (the centre of the plug should be positive). Make sure also that REG1 is correctly oriented and that all leads have been correctly soldered to their PCB pads.

If the supply checks out, switch off and install IC1, making sure that its notched end faces towards LED10 and that all its pins go into the socket correctly. That done, reapply power and check that the hand-held remote can activate each output.

By the way, you will need to insert a CR2025 cell into the remote before using it. The cell's tray is accessed from the bottom edge of the case. It's opened by first pulling its locking tab sideways (towards the centre) and then sliding the tray out (it may require some force to move it). The cell is then installed with its negative side towards the pushbutton (top) side of the case.

By default, the outputs are all configured for momentary operation. **If you want toggle operation for an output, press and hold S1 on the receiver's**

Driving devices using the open collector outputs

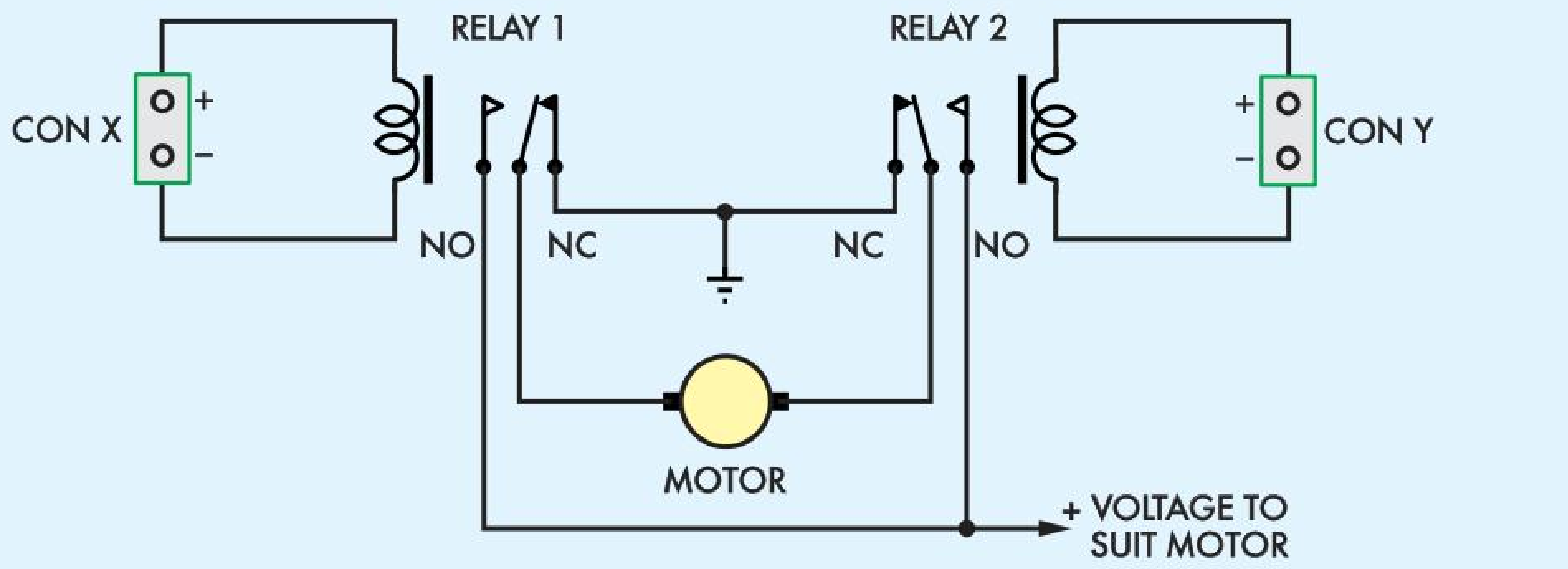


Fig.11(a): using two open-collector outputs to drive a motor in both directions:

(1) Both outputs set for momentary operation

Pressing (and holding) the button for open-collector output 'X' activates Relay 1 and causes the motor to rotate one way, while pressing the button for output 'Y' activates Relay 2 and causes the motor to rotate the other way.

(2) Both outputs set for toggle operation

The motor will be stopped until one of the outputs is toggled (its direction will depend on which output is turned on). The motor can then be reversed by toggling both outputs or stopped by toggling either output.

(3) One output set for toggle and the other momentary operation

The motor will run continuously in one direction if the toggle output is on or in the other direction for as long as the momentary output is on while the toggle output remains off (ie, it runs while the button on the remote is pressed).

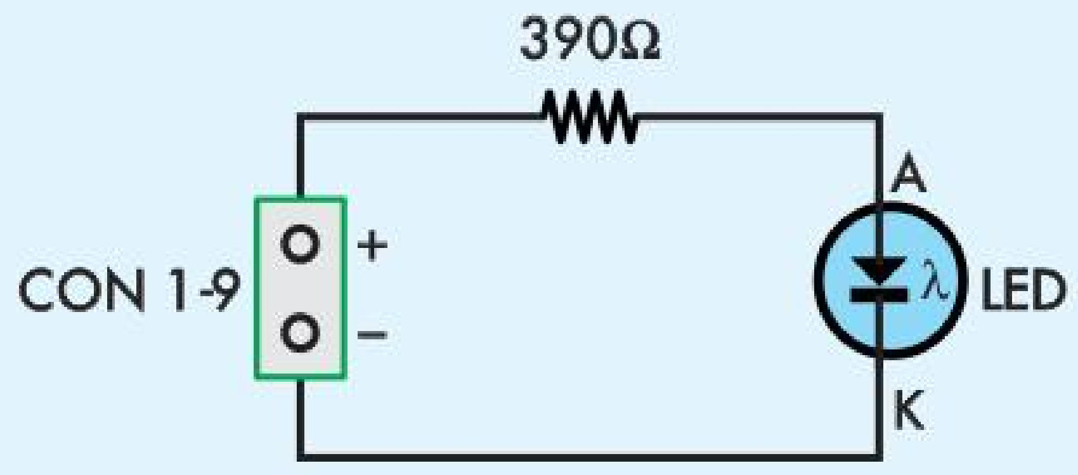


Fig.11(b): driving an LED output.

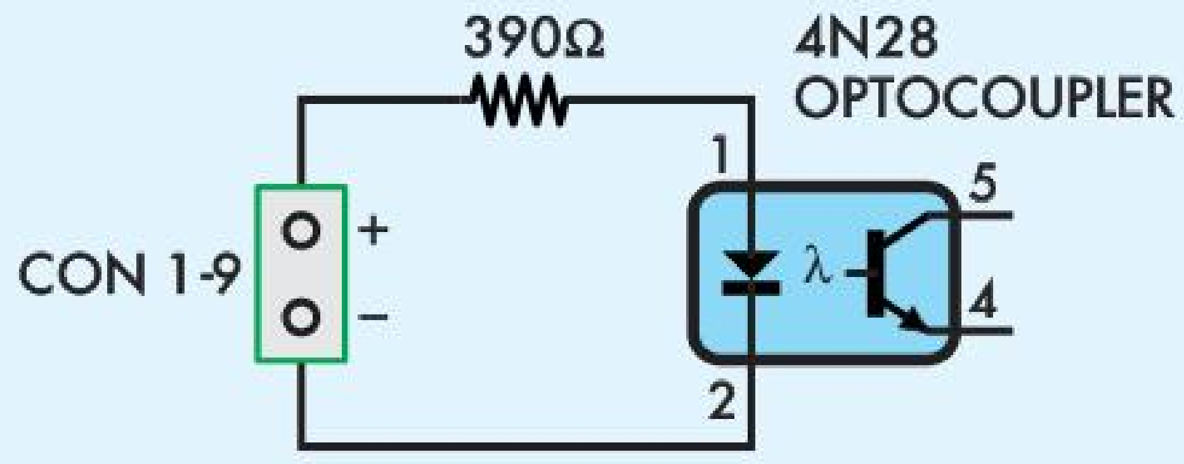


Fig.11(c): driving an optocoupler.

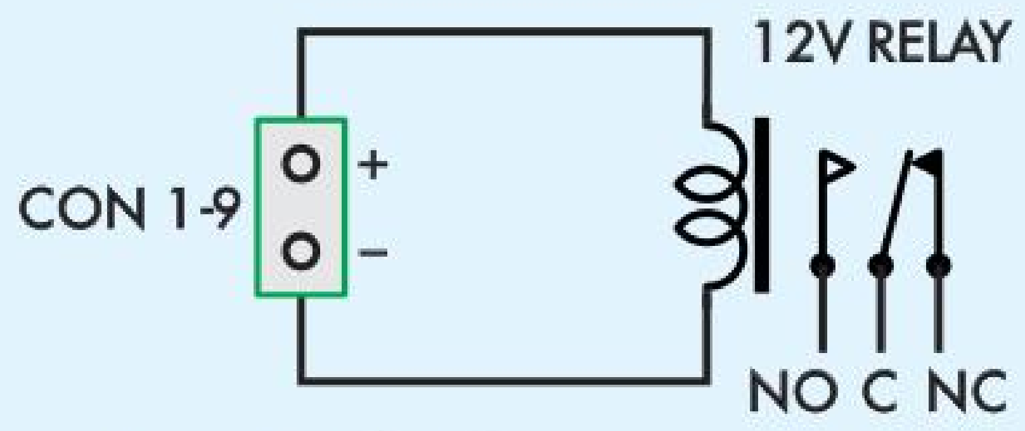


Fig.11(d): driving a 12V relay.

PCB, then press the required button on the remote and release S1. Switching back from toggle to momentary operation is done the same way

If you find that the unit doesn't operate reliably, or only works with certain orientations of the remote, it may be due to frequency tolerances. In that case, it's just a matter of altering IC1's frequency to improve the IR code detection. The accompanying panel (*Compensating for frequency tolerances*) describes how that's done.

If the unit fails to work, check your soldering and also check that all the parts have been correctly placed and oriented.

Front panel

Assuming that it's all working correctly, all that remains now is to fit the front panel. As shown in Figs.6(a) and 6(b), there are two to choose from. Use Fig.6(a) if you are simply using the unit to control nine output channels and don't need device selection (ie, you don't need to select another receiver).

Alternatively, if you are using device selection (eg, you have two or more receivers), use the front panel shown in Fig.6(b). Don't forget that you will need to install a jumper on the 3-way pin header (near IC1) on the PCB to select either device A, B or C.

An accompanying panel describes how to make a front panel using clear film or a Dataflex or Datapol sticky label. Once you have the label, remove the PCB from the case, then affix the label in position and cut out the holes using a sharp hobby knife.

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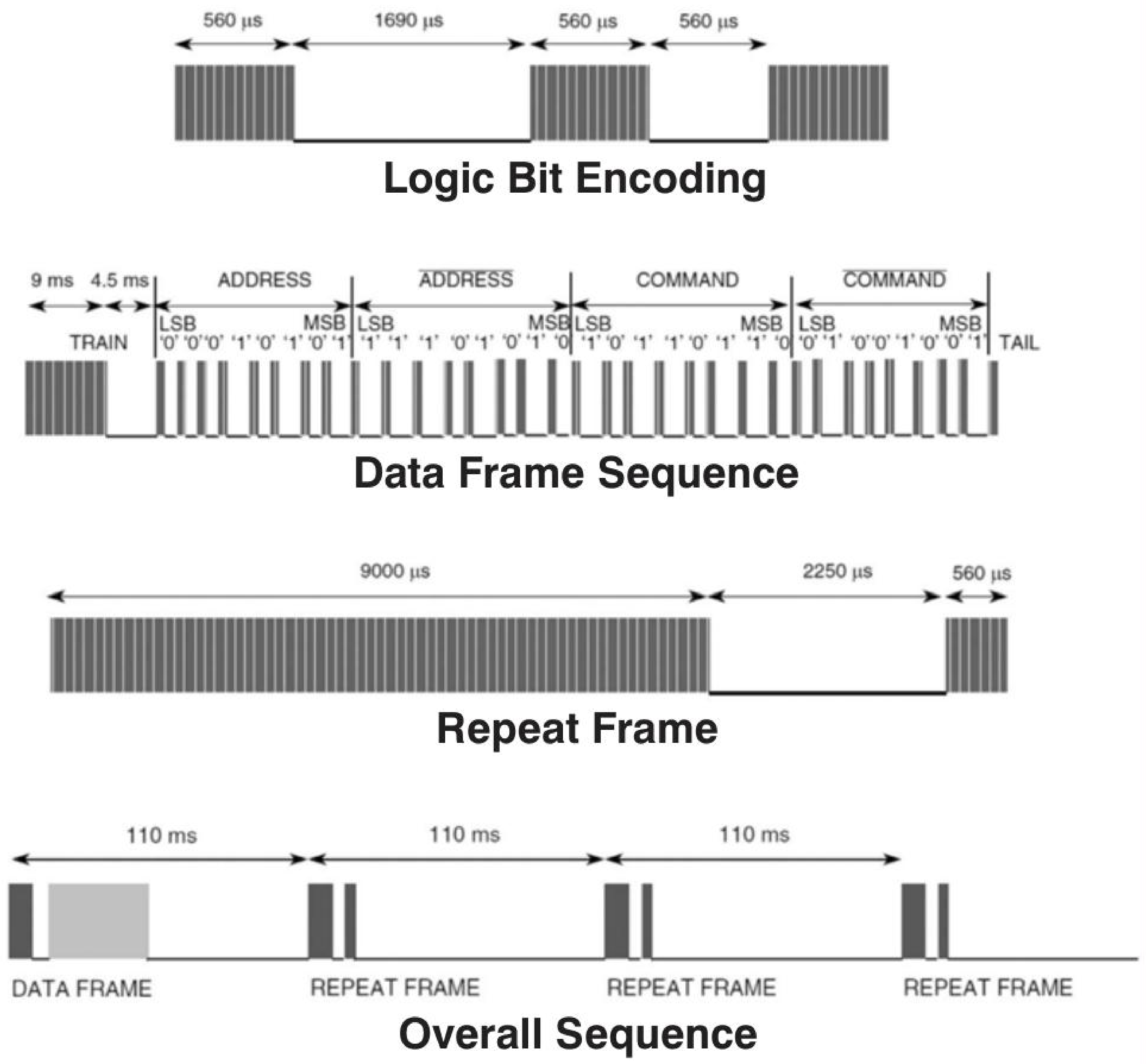
Pulse Distance Protocol (PDP)



Logic Bit Encoding

Data Frame Sequence

Repeat Frame

Overall Sequence

Fig.12: the basics of the Pulse Distance Protocol (PDP). The data stream consists first of the address bits and then the command bits (see text).

Most infrared (IR) controllers use a modulation frequency between 36kHz and 40kHz – typically 38kHz. This is the frequency at which an infrared LED is switched on and off when a signal code is sent to the receiver.

A series of 38kHz signal pulses is called a 'burst' and is inter-spaced with a pause, during which no IR signal is sent. This series of bursts and pauses usually conforms to a particular format or 'protocol' and there are several in common use. These include the Manchester-encoded RC5 and RC6 protocols, as used by Philips, while Sony uses the Pulse Width Protocol.

By contrast, the remote used in this project uses NEC's Pulse Distance Protocol. For further details on all these protocols, see application note 'AN3053' by Freescale Semiconductor (formerly Motorola): **http://cache.freescale.com/files/microcontrollers/doc/app_note/AN3053.pdf**

Fig.12 shows the basics of the Pulse Distance Protocol. Logic 1 and logic 0 both comprise an initial 560µs-long 38kHz burst. Each logic 1 is followed by a 1690µs pause, but a logic 0 is followed by a shorter 560µs pause (ie, the same length as the logic 0's 38kHz burst).

The entire data stream uses a 9ms burst and a 4.5ms-pause starting train. The following data consists first of the address bits and then the command bits. The address identifies the hand-held remote; the command bits correspond to the buttons on the remote.

Note that the address and command data is sent with the least-significant bit transmitted first. The data comprises an 8-bit address, after which a complementary 8-bit address is sent. This is essentially the opposite bit of the address that's sent. So for every '0' bit that's sent in the address, a '1' will be sent in the complementary address. Similarly, for every 1 that's sent in the address, a 0 will be sent in the complementary address. The command bits are also resent in complementary form.

As an aside, if you look up the address and command values that the remote produces (see: **https://learn.sparkfun.com/tutorials/ir-control-kit-hookup-guide**), you will see that the address is 10EF hex. In addition, the operate button code is D827 hex.

10 hex is the address value and EF hex is the address complement value. These values are in hexadecimal format (ie, values from 10-15 are designated A-F).

The complementary address and command bytes are sent so that they can be compared to detect errors. If the complementary data value received doesn't match the complement of the data value received, the signal has been corrupted somehow (eg, due to interference). Alternatively, the received data may not be PDP protocol data, which means that the signal is being sent by a different hand-held remote.

Following the address and command data, an end (or tail) comprising a 560µs burst is sent to complete the data frame. Any further holding of the hand-held remote's button will then produce a repeat frame. This consists of a 9ms burst followed by a 2.25ms pause and then a 560µs burst.

The repeat frame is repeated at 110ms intervals whenever the remote's button is held down.

Output connections

The reed relays are ideal for switching low voltages (up to 24V maximum) and currents up to 500mA. They can be used to duplicate pushbutton switches on equipment by wiring the reed relay output in parallel with the switch.

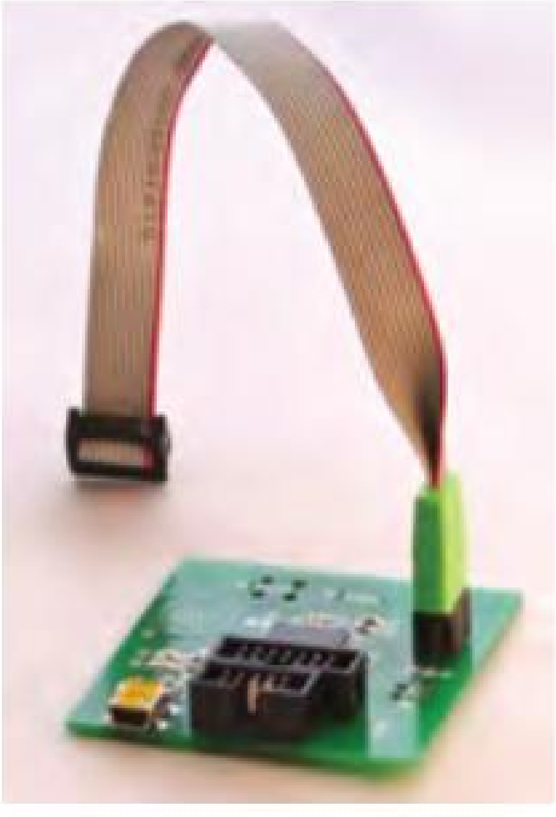
If switching inductive loads, then a reverse-biased diode should be connected across the relay's contacts.

Do not under any circumstances use the on-board reed relays to switch mains voltages. That would be dangerous since neither the relays nor the PCB tracks are designed to handle high voltages.

If you need to switch high voltages, use either the reed relay or the open-collector transistor outputs to switch appropriately-rated external relays.

Tag-Connect

MPLAB ICD 3
MICROCHIP



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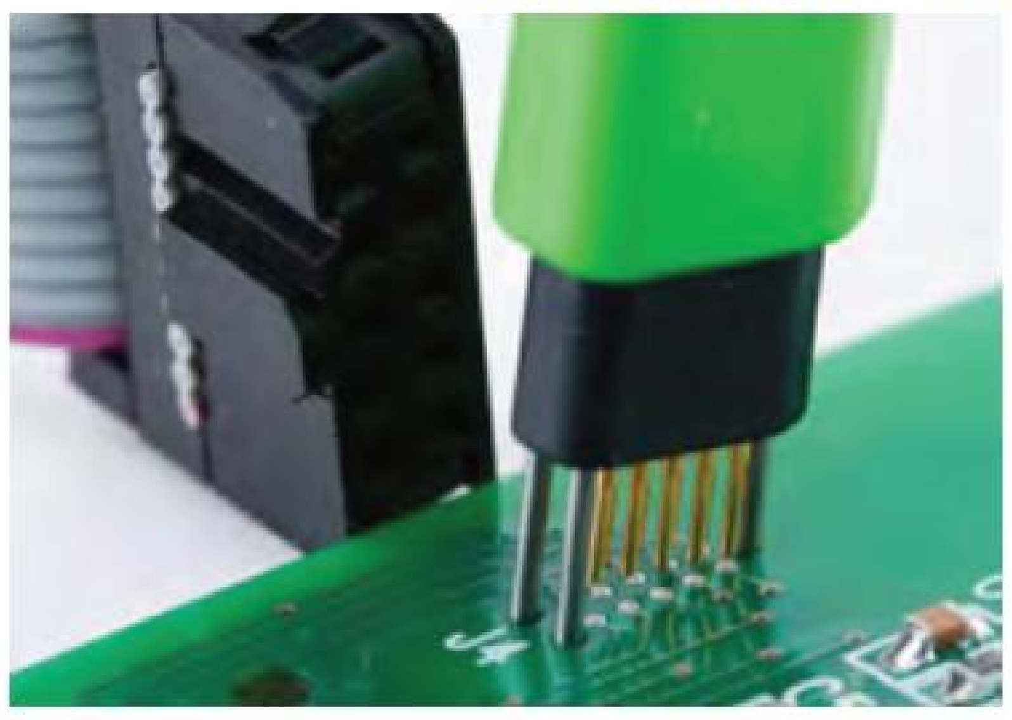

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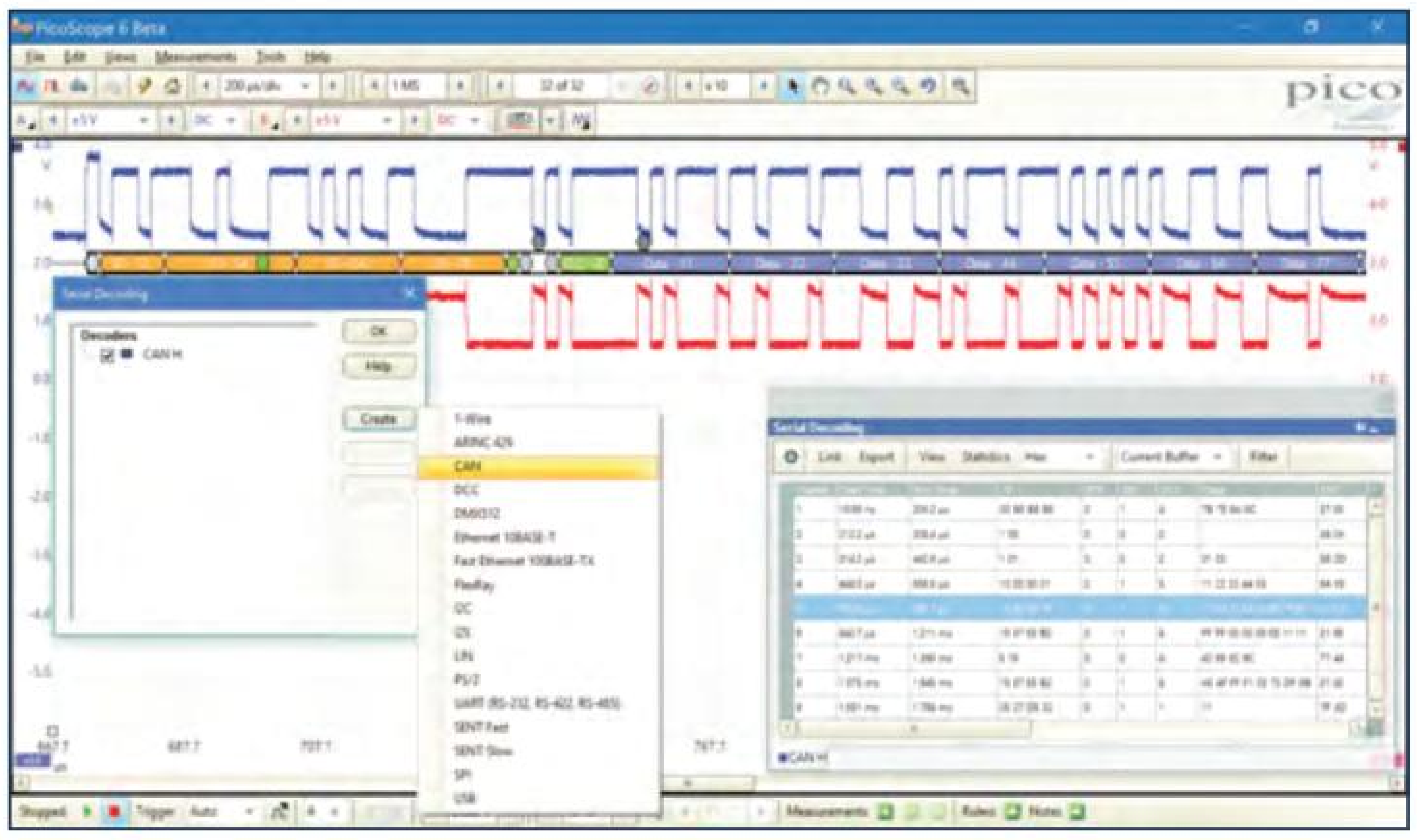

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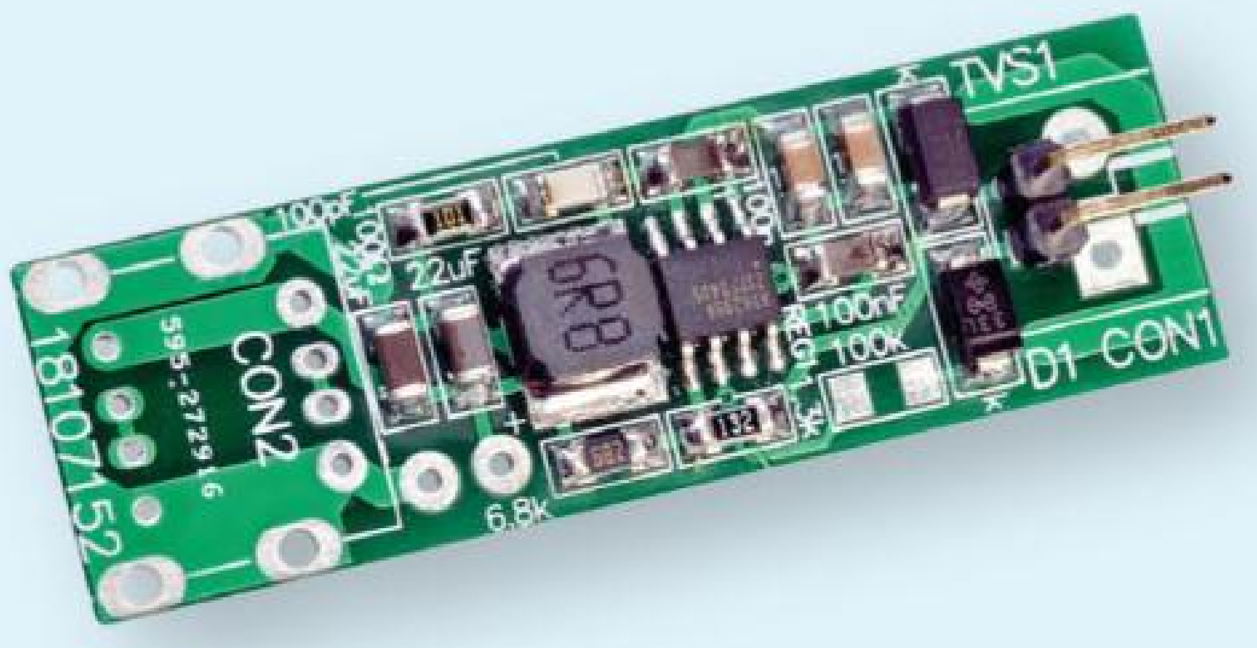
Revised USB Charger Regulator with Low Battery Cut-Out



This revised version of the tiny USB charger module presented in the July 2016 issue now has extra circuitry to prevent a USB device such as a permanently connected dash-camera from discharging the car's battery below 12.15V. We've boosted the continuous output current from 2.5A to 3A, and as well as being installed in a motor vehicle, it could be built as a portable USB device charger or for many other purposes.

By Nicholas Vinen

WE'VE HAD a good response to our article in the July 2016 issue on installing USB charging points in a car. One of the benefits of that approach is that the USB sockets are powered even when the vehicle ignition is off, allowing phones and similar devices to be left charging while the car is parked.

That brings up the risk of draining the vehicle battery if those devices are left plugged in long-term, which was discussed in the July article. Basically, the stated solution was to avoid connecting anything permanently if it draws a lot of current from the USB socket on a continuous basis.

One reader asked why we didn't simply incorporate a low-battery cut-out in the circuit to address this. The simple answer is that we were trying to minimise both the complexity of the design and the cost of building the unit. Had the switchmode regulator IC used in that project incorporated a programmable under-voltage lock-out feature (as some do), we would have used it, but unfortunately the RT-8299A, despite its other good points, does not.

The RT8299A does have an enable input (pin 6) but this is designed to be driven with a logic signal and it has a low and ill-defined threshold voltage; thus we can't use a resistive divider to set any kind of accurate threshold. An external voltage reference and comparator are therefore required.

Features and Specifications

Maximum sustained input voltage: 15V

Low-battery cut-out: 12.15V

Battery cut-in voltage: 12.86V

High efficiency: typically >90%, 0.5-2A

Output voltage range: 0.8-15V, typically 5V (must be at least 2V below input)

Output current: up to 3A

Quiescent current: approximately 1mA

Current with low-battery cut-out engaged: typically <10μA

Output ripple and noise: ~5mV RMS @ 1.2A

Load regulation: ~150mV/A, 0-250mA; ~75mV/A, 250-3000mA

Line regulation: <1mV/V

Transient response: output stabilises within ~20µs for a ±1.2A load step

Other features: transient voltage suppression, no heatsinking necessary, soft start, output short-circuit protection, output over-current protection, overheating protection

Circuit description

The revised circuit is shown in Fig.1. The top part is basically identical to the original USB charger circuit shown on page 29 of the July 2016 issue, with one small change we'll get to later. The added section below is derived from the *Battery Lifesaver* circuit shown on page 30 of the September 2014 issue.

The incoming 12V supply connects to linear low-dropout regulator REG2, which provides both the power supply and an accurate reference voltage to micropower comparator IC1. REG2 has an output voltage tolerance of ±0.4%.

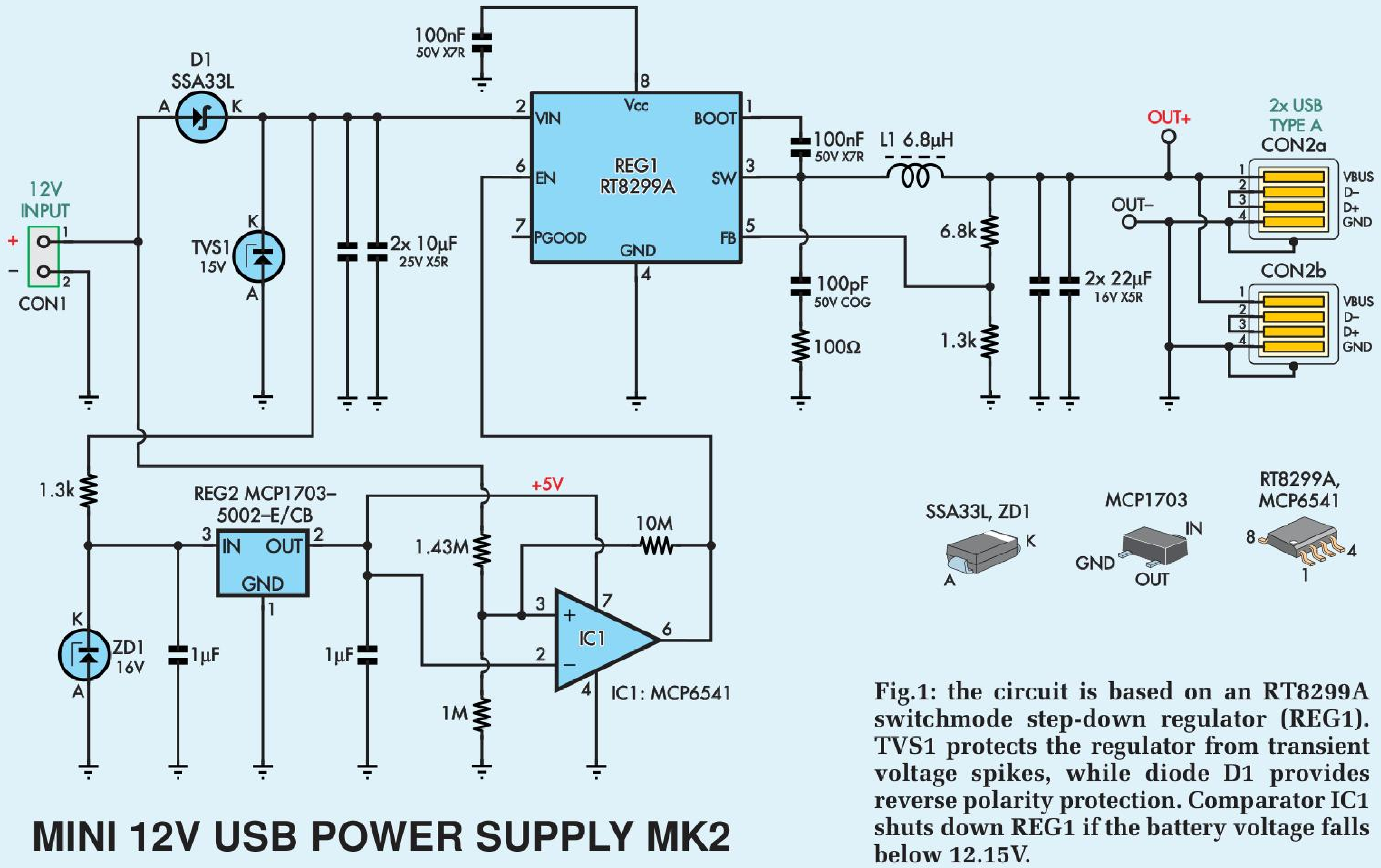


Fig.1: the circuit is based on an RT8299A switchmode step-down regulator (REG1). TVS1 protects the regulator from transient voltage spikes, while diode D1 provides reverse polarity protection. Comparator IC1 shuts down REG1 if the battery voltage falls below 12.15V.

The battery voltage is divided by two resistors, 1.43MΩ and 1MΩ.

These values are chosen so that the voltage at the non-inverting input (pin 3) of IC1 drops below the 5V reference at pin 2 once the supply voltage drops below 12.15V. The 10MΩ resistor provides about 0.75V hysteresis, so that if the unit switches off due to a low vehicle battery voltage, it won't switch back on until the battery rises above 12.86V; ie, the next time the engine is started and the battery starts to charge.

So the output of IC1 is high when the battery voltage is sufficiently high and low otherwise. This output goes to the enable pin (pin 6) of REG1 to shut the regulator down when the battery voltage is low. The 100kΩ pull-up resistor originally provided for the EN pin is no longer needed, although we've left the pads on the PCB. This allows the original circuit to also be built on this PCB, in which case REG2, IC1 and their associated components are simply omitted.

Added protection

ZD1 and its associated 1.3kΩ resistor are not shown on the photo of the prototype. They were added to the final version to better protect REG2 against supply spikes, which are common in vehicles. This is necessary because while TVS1 clamps REG1's supply below its 24V maximum, this is too high for REG2 to handle, with its maximum rating of 18V.

Since ZD1 has a breakdown voltage of 16V, it will not conduct with normal automotive battery voltages (12-15V) but will protect REG2 during the worst spikes. Its leakage current at normal operating voltages is negligible.

When the EN pin of REG1 is pulled low and its output is shut down, it draws less than 3μA. REG2 consumes around 2μA and IC1 around 0.7μA. There's a further 5μA through the battery sense resistive divider for a total of around 10μA. This is well below the self-discharge current of a car battery and a tiny fraction of the load a typical modern vehicle puts on its battery with the ignition switched off.

Note that 1.43MΩ seems like an odd value for a resistor, but it is in the E96 series and is easy enough to get. Failing that, you can parallel 5.1MΩ and 2MΩ resistors (both E24 values). Paralleling SMD resistors is easily done since they can be soldered on top of one another.

Step-down regulator

In the July 2016 issue, we explained in detail how switchmode regulator REG1 works. In brief, the voltage at pin 3 (SW) toggles between 0V and the incoming supply voltage (ie, that at pin 2, V_{IN}). When pin 3 is high, current flows through inductor L1 into the output filter capacitors and the load, charging up L1's magnetic field. When pin 3 is driven low, this magnetic field begins to collapse and as as result, current continues to flow into the load, but this time it's pulled from ground via pin 4.

The duty cycle of the square wave output at pin 3 is controlled so that the average voltage at the load is very close to 5V. This is determined by sampling the feedback voltage at pin 5 (FB), which comes from a 6.8kΩ/1.3kΩ resistive divider across the output. When the output voltage is 5V, the feedback voltage is 0.8V and this matches REG1's internal reference. If the feedback voltage is too low, REG1 increases the duty cycle and if it's too high, the duty cycle is reduced.

The capacitor between pin 3 and pin 1 (BOOT) is used to generate a voltage of around 10V (the output

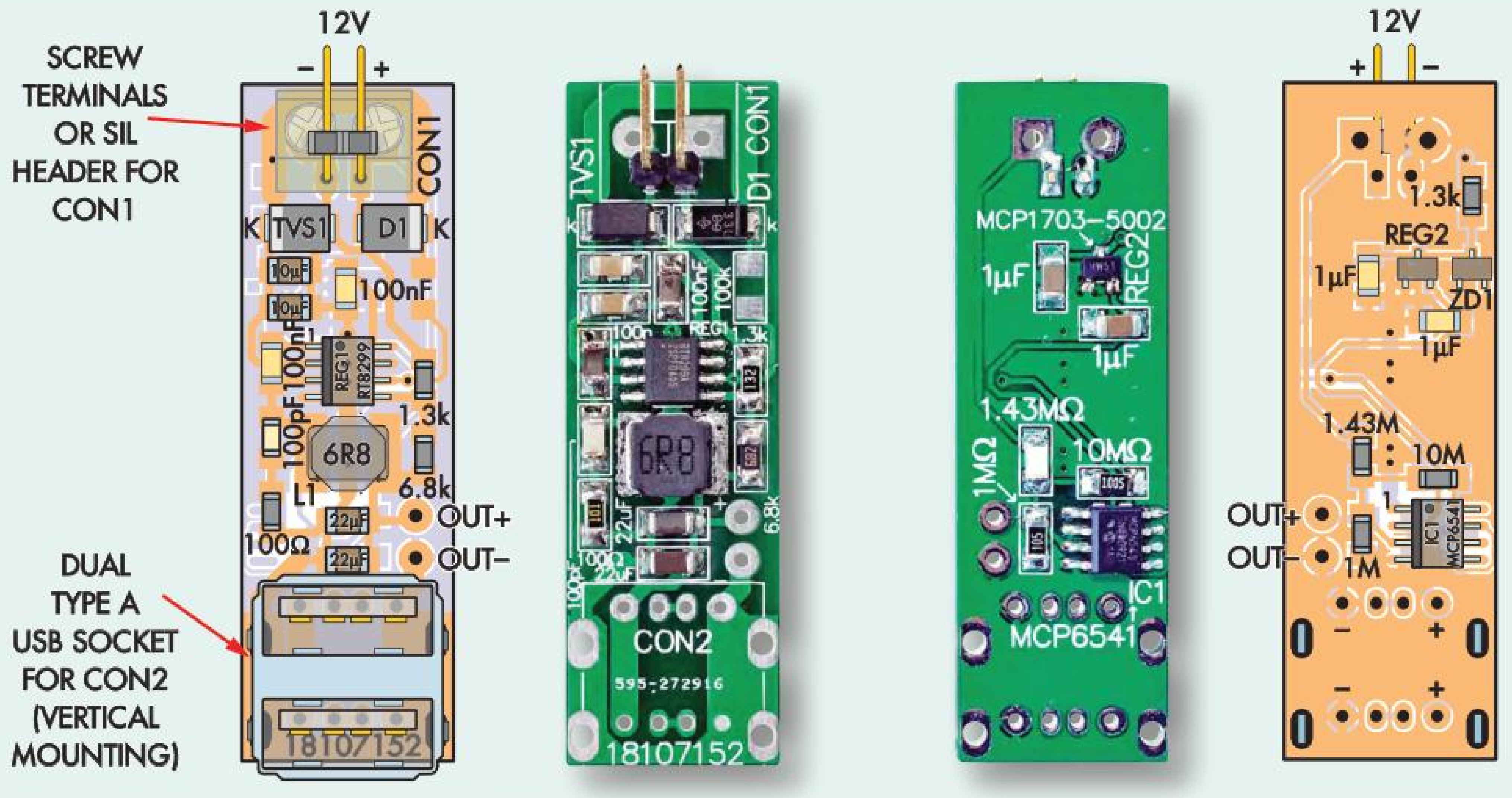


Fig.2: follow these top and bottom layout diagrams and the photos to assemble the PCB. Take care with the orientation of REG1, TVS1 and D1 on the top and REG2, IC1 and ZD1 on the bottom. Note that the photos show a prototype PCB.

voltage plus 5V) which REG1 uses to drive the gate of its internal MOSFET in order to pull pin 3 high. The series capacitor and resistor from pin 3 to ground form a snubber to reduce the rate of voltage change at this pin, cutting down on EMI.

Increased output current

The literature provided for REG1 suggests a filter inductor value of around 2.2µH. Choosing switchmode inductor values can be quite tricky as there are trade-offs. The advantage of low values such as the 2.2µH suggested is that since they require fewer turns of wire, the wire can be shorter and thicker, thus lowering resistive losses. They can also be physically smaller both due to less wire and a smaller core.

However, lower inductance does mean more output ripple voltage, while changing the inductor value changes the time constants in the switchmode feedback loop and can affect stability and transient response.

The 10µH inductor specified for the original version of this circuit has a continuous current rating of around 2.5A. This time, we tried a similarly-sized 6.8µH inductor with a 3A continuous current rating and a saturation current of 3.9A. Thus we can now obtain the full 3A output specified for REG1 while the ripple level is still very low.

Along with the PCB, there is a kit of parts for the original USB charger project that includes all the SMDs. Likewise, for this revised version there is a kit that includes the new inductor plus the extra components for the low-battery cut-out – see Parts List.

Changing the voltage thresholds

The 12.15V threshold will suit most lead-acid, AGM or SLA/gel cell batteries and should leave sufficient charge to start a motor. However, it's possible some constructors will want to change this, eg, if powering the unit with a Li-ion, LiPo or LiFePO4 battery instead. The easiest way to do this is to replace the 1.43MΩ resistor with a different value – if necessary, by paralleling two standard values.

For a desired cut-out threshold V_{co}, calculate the required value R_{div} in ohms as:

$$\mathbf{R_{div} = (V_{co} - 5V) \times 200{,}000}$$

and pick the nearest value available. For example, for a 12.5V threshold, use a 1.5MΩ resistor. Calculate the threshold from the chosen resistor value as:

$$\mathbf{V_{co} = (R_{div} / 200{,}000) + 5V}$$

The cut-in threshold V_{ci} is then:

$$\mathbf{V_{ci} = (R_{div} / 181{,}818) + 5V}$$

If you need to lower this (ie, reduce hysteresis), increase the value of the 10MΩ resistor; 15MΩ, 22MΩ and 33MΩ SMD resistors are available. Alternatively, to increase hysteresis, lower the value of the 10MΩ resistor. The hysteresis voltage V_h for a feedback resistor R_{fb} is calculated as:

$$\mathbf{V_h = (V_{co} - 5V) \times 1{,}000{,}000 / R_{fb}}$$

For the value specified, this gives 0.715V. If you need a particular cut-in voltage, calculate the resistor value:

$$\mathbf{R_{fb} = (V_{co} - 5V)/(V_{ci} - V_{co}) \times 1{,}000{,}000}$$

Once again, you will have to pick the closest value you can actually get.

Construction

Fig.2 shows the new component overlay diagrams. The top side is virtually identical to that shown in the July issue; all the extra parts have been added to the bottom. The revised PCB is available from the *EPE PCB Service*, coded 18107152 and measures 16 × 51mm. It's easiest to fit all the components to the top side of the board first.

Start by fitting REG1. While an SOIC-8 package is generally easy to solder, this one has a thermal pad on the underside, which is also supposed to be soldered to the board. To do this properly, you need to use a hot-air rework station. These are available from eBay sellers for around £25 (eg, search for 'Atten 858d').

If you have one of these, simply apply some solder paste to each pad, place the IC on top, check its orientation carefully (pin 1 to upper left) and then heat the IC and its leads until the solder reflows. Be sure to continue heating it long enough for the solder on the thermal pad to melt also; you can usually see fumes from the flux escaping under the IC.

While we recommend this method and it's how we built this prototype, it is possible to solder the chip by hand. To do this, first place a small amount of non-conductive (silicone-based) heatsink paste on the central pad and clean the residue off the other pads. Then tin one of the eight remaining pads, carefully place the IC in position and reheat that pad while pressing down gently on the IC until its lead contacts the PCB.

Once it's in place, check the alignment, then solder the remaining seven pins and add some solder to that first pin to refresh the joint. Any solder bridges between pins can then be easily cleaned up using solder wick.

Note that it's best to avoid moving the IC by much during soldering, so that the heatsink paste is not spread around. Also, don't clean the board using any solvents as these are likely to wash the paste away. We used the hand-soldering method successfully when building the original version shown in our July issue.

One of the most common problems with soldering an IC like this is that it's possible to get solder on a pin without it actually flowing onto the corresponding pad. As a result, it's best to check all eight leads under a magnifying lamp to make sure the solder fillets have properly formed.

With REG1 in place, inductor L1 is next. This is a little tricky due to its high thermal inertia. There are various methods, but the simplest is to treat it like a large chip component. This involves adding a fair bit of solder to one of the pads, enough that it's visibly built up, then heating this solder while sliding L1 into place along the surface of the PCB. It's easiest to do this while holding it with angled tweezers.

As soon as L1 hits the solder, some of it will cool and solidify. You will have to hold the iron in place while L1 heats up and the solder will then re-melt. Once that happens, you can finish sliding L1 across into the correct position between the two pads. You can then flow solder onto the opposite pad.

Note that it's best to do this immediately before L1 cools down. Note also that it will take a little while to apply enough heat to form a good joint.

You will then need to go back and add some more solder and heat to the initial pad, until you get a similarly good fillet on that side; much of the flux will have boiled off during the initial soldering process.

Alternatively, use solder paste and a hot air wand, although you will probably need to hold the inductor in place using steel tweezers or the hot air may blow it out of position.

The rest of the components are easier as they are substantially smaller but you can use the same basic idea of adding solder to one pad and then sliding the part into place. The only remaining polarised components are D1 and TVS1; in each case, the cathode (striped) side goes towards the nearest edge of the PCB.

Don't get any of the different value capacitors, resistors or diodes mixed up. The resistors will have printed value codes on the top, but the other components are likely to be unmarked so you will have to remove them from their packaging one at a time and immediately solder them to the PCB.

Parts List

1 double-sided PCB, available from the *EPE PCB Service*, coded 18107152, 16 × 51mm
1 6.8µH 3A RMS (3.9A saturation) 6×6mm SMD inductor (L1)
1 2-way mini terminal block or pin header (CON1) (optional)
1 dual-stacked vertical type-A USB socket, through-hole mounting (CON2) OR
2 vertical or horizontal type-A USB sockets, through-hole mounting (CON2)
1 50mm length of 20mm-diameter heatshrink tubing

Semiconductors
1 RT8299AZSP 3A switchmode step-down regulator IC (REG1)
1 MCP1703AT-5002-/CB or MCP1703T-5002-/CB 5V LDO regulator (REG2)
1 MCP6541-(I/E)/SN micropower comparator (IC1)
1 3A 30V Schottky diode, DO-214AC (D1)
1 SMAJ15A SMD 15V 400W TVS or equivalent (TVS1)
1 BZX84B16 16V 0.25W zener diode (ZD1)

Capacitors (all SMD 3216/1206*)
2 22µF 16V X5R/X7R
2 10µF 25V X5R/X7R
2 1µF 50V X7R
2 100nF 50V X7R
1 100pF 50V C0G/NP0

Resistors (SMD 3216/1206*, 1%, 0.25W)
1 10MΩ
1 1.43MΩ
1 1MΩ
1 6.8kΩ
2 1.3kΩ
1 100Ω
*2012/0805-size parts also suitable

Visit **www.siliconchip.com.au/Shop/8/3096** for parts.

Bottom-side components

Now you'll need to flip the board over – but it won't sit straight due to the components sticking up, especially L1. To solve this, get two heavy objects of the same thickness (eg, timber offcuts) and space them apart on your bench so that each end of the board can rest on one or the other, with the components hanging down in the gap in between.

Now solder IC1 in place. This is similar to REG1, but doesn't have a thermal pad, so you can simply tin one pad, slide it into place while heating that pad, then solder the rest of the pins. Be sure that its pin 1 dot is oriented as shown in Fig.2 and clean up any solder bridges between pins using solder wick and a small amount of flux paste.

Next, fit REG2 and ZD1, which are both in SOT-23 packages; don't get them mixed up. It's then just a matter of installing the remaining passives where shown, ie, four SMD resistors and two 1µF ceramic capacitors.

Connectors

The PCB has provision for a pin header or terminal block as the power input, or you can solder wires to the two pads – to check the polarity, see Fig.2.

For the outputs, there is space for one or two on-board USB sockets, either a vertical or horizontal type-A USB socket, or a vertical dual type-A USB socket. However, as explained in the July issue, many constructors will prefer to run wires from the OUT+ and OUT– pads to one or more surface-mounting USB sockets, depending on the exact application.

There were also detailed instructions in the July 2015 issue on how to install the unit in the overhead binnacle in a typical modern motor vehicle. We also explained back then that, should you wish to use the PCB as a general-purpose 3A step-down regulator, you could change the 6.8kΩ feedback resistor to obtain any output voltage from 0.8V up to about 10V.

Should you wish to do this, the new resistor value is simply calculated as:

$$R = ((V_{out} \div 0.8) - 1) \times 1.3k\Omega$$

If you plug 5V into this formula you will see that the result is very close to the 6.8kΩ value specified.

Finally, check that the unit works, ie, gives a 5V output for a 13-15V input, then encapsulate it in heatshrink tubing to protect it and prevent short circuits.

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Teach-In 2016

Exploring the Arduino

Part 11: Global Positioning System

by Mike and Richard Tooley

Welcome to *Teach-In 2016 – Exploring the Arduino*. This exciting new series has been designed for electronics enthusiasts wanting to get to grips with the immensely popular Arduino microcontroller as well as coding enthusiasts who want to explore hardware and interfacing. So, whether you are considering what to do with your Arduino, or maybe have an idea for a project but don't know how to turn it into reality, our new *Teach-In 2016* series will provide you with a one-stop source of ideas and practical information.

Last month, *Teach-In 2016, Arduino World* looked at ultrasonic sensors. *Arduino Workshop* explained the practical aspects of object proximity and distance sensing and our programming feature, *Coding Quickstart* introduced the NewPing ultrasonic rangefinder library. Our *Get Real* project concluded with the design and construction of a proximity warning system based on the Arduino and a low-cost ultrasonic transmitter/receiver module.

This month

In this month's *Teach-In 2016, Arduino World* will be looking at Global Positioning System (GPS) modules for use with the Arduino. *Arduino Workshop* will introduce you to the practical aspects of using GPS, while our programming feature, *Coding Quickstart* will show you how to use the Arduino GPS library. Our *Get Real* project this month is devoted to the design and construction of a simple Arduino-based GPS unit that will allow you to display your current longitude and latitude precisely.

Arduino World: GPS modules

The advent of low-cost, widely available Global Positioning System (GPS) receiver modules has made it possible to add exciting features to microcontroller applications. For example, recording accurate position data so that objects can be tracked. Not only is it possible to provide a location fix, but also values for altitude, speed, bearing, distance and time. This can add a completely new dimension to your Arduino and other microcontroller applications.

GPS modules usually comprise of a GPS receiver chip and GPS antenna (or a connector for an external active antenna) together with the necessary serial interfacing logic (ie, a UART) and power conditioning circuitry. They are available at low cost from a number of suppliers, both here in the UK, US and also the Far East. Dedicated Arduino GPS shields are also available, but they tend to be a little more expensive.

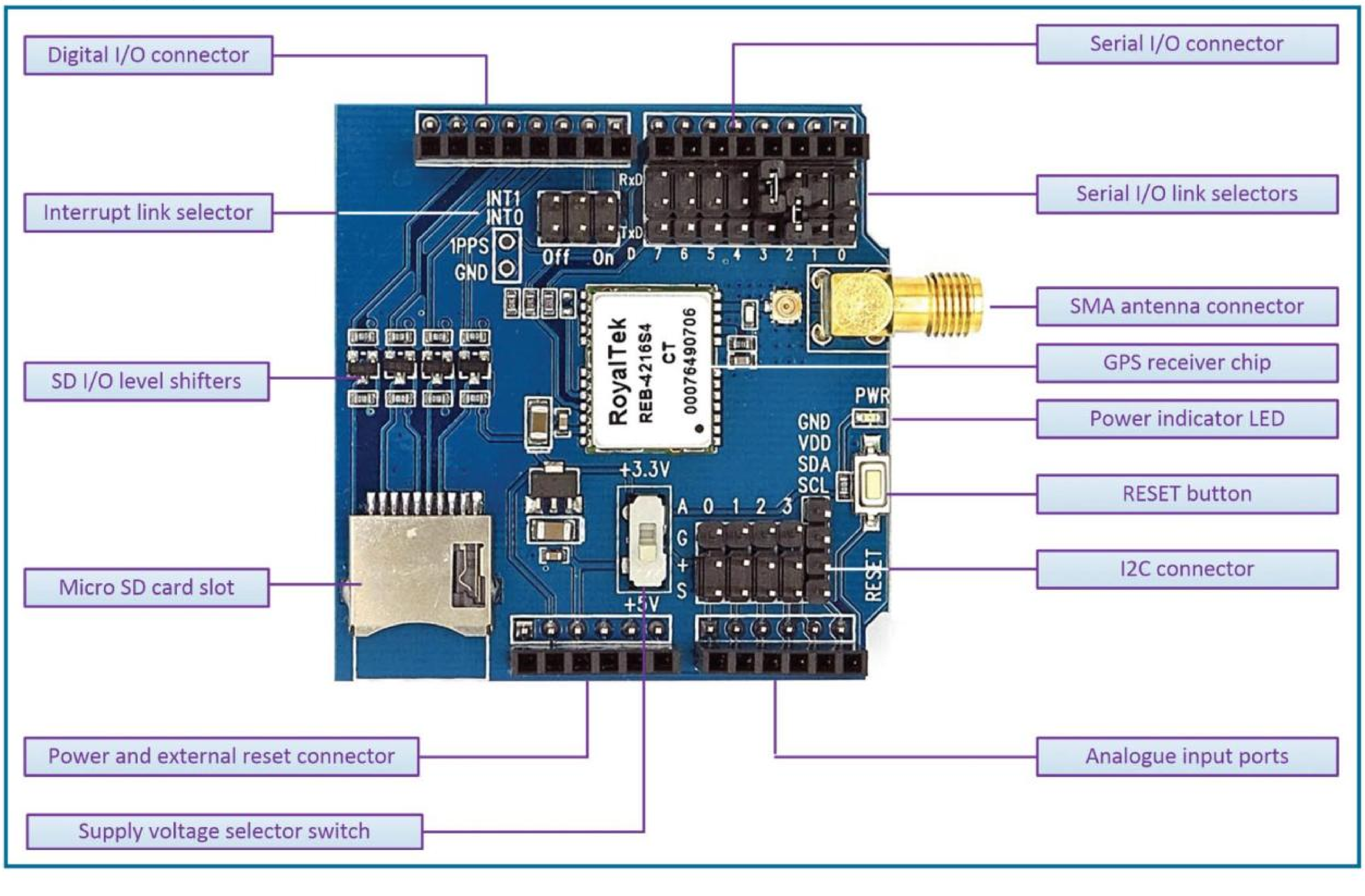

Digital I/O connector
Interrupt link selector
SD I/O level shifters
Micro SD card slot
Power and external reset connector
Supply voltage selector switch
Serial I/O connector
Serial I/O link selectors
SMA antenna connector
GPS receiver chip
Power indicator LED
RESET button
I2C connector
Analogue input ports
RxD
TxD
INT1
INT0
1PPS
GND
Off
On
D 7 6 5 4 3 2 1 0
RoyalTek
REB-4216S4
CT
00076490706
PWR
GND
VDD
SDA
SCL
+3.3V
+5V
A 0 1 2 3
G
+
S
RESET

Fig.11.2. Layout of an Arduino GPS shield

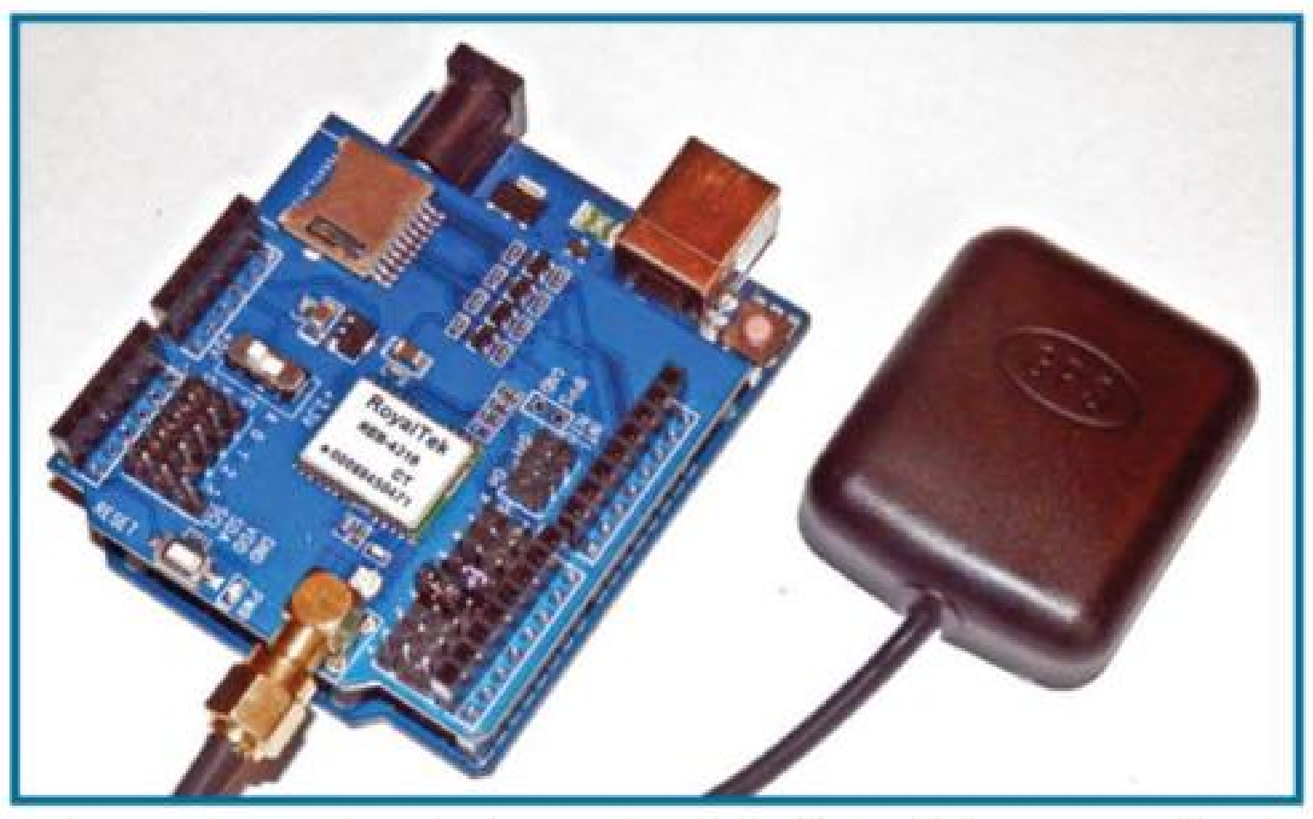


Fig.11.1. Arduino GPS shield, complete with active antenna

A dedicated Arduino shield can provide an instant solution to the acquisition of GPS data and uses an absolute minimum of external wiring (often just an antenna connecting cable). One such device is shown in Fig.11.1. This module is based on a RoyalTek REB-4216 GPS receiver, and it offers a footprint that is compatible with Arduino Uno and MEGA boards. Serial data from the GPS module can be configured using selectable links and connected to two of the lower eight digital

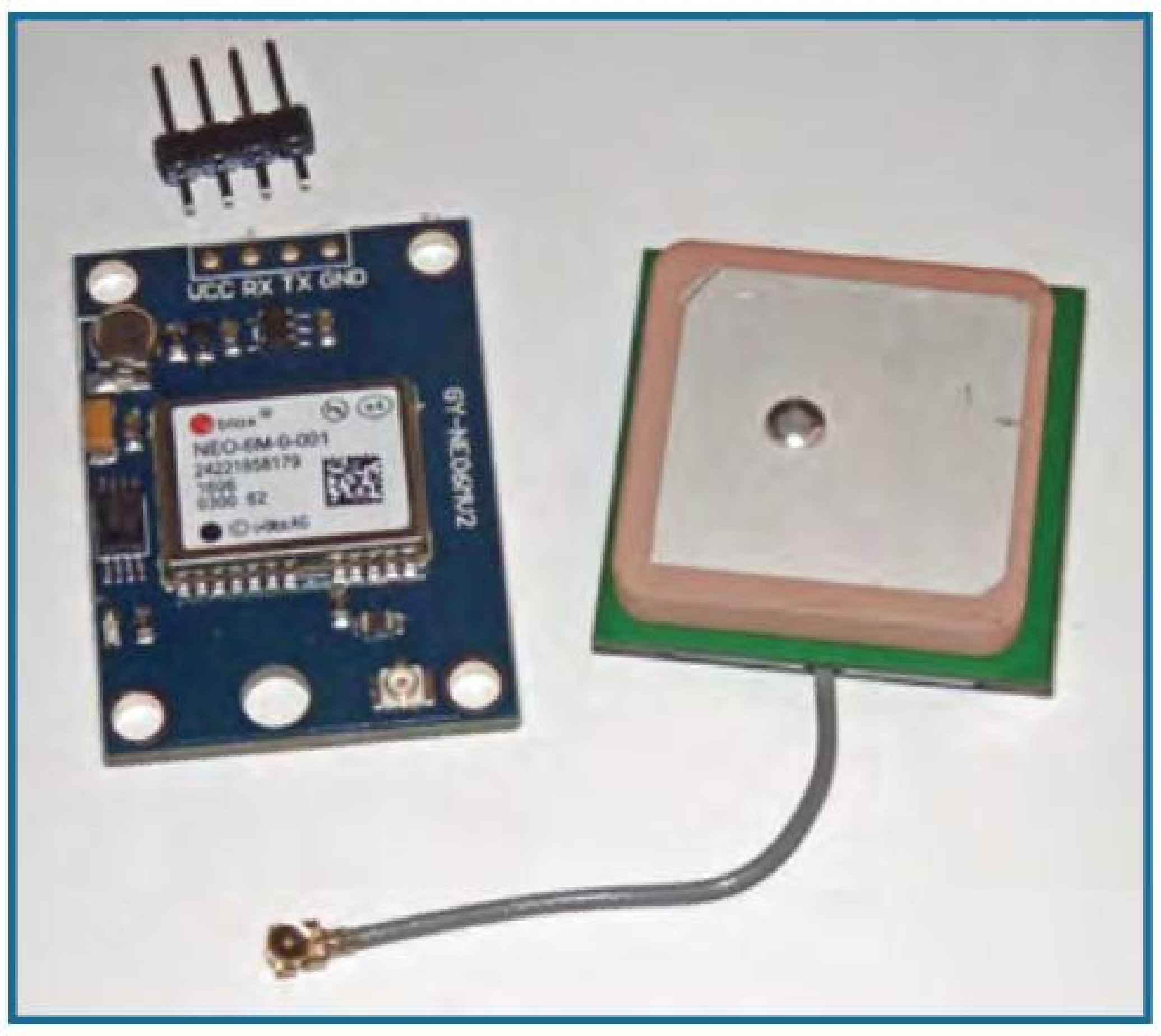


Fig.11.3. GPS receiver module

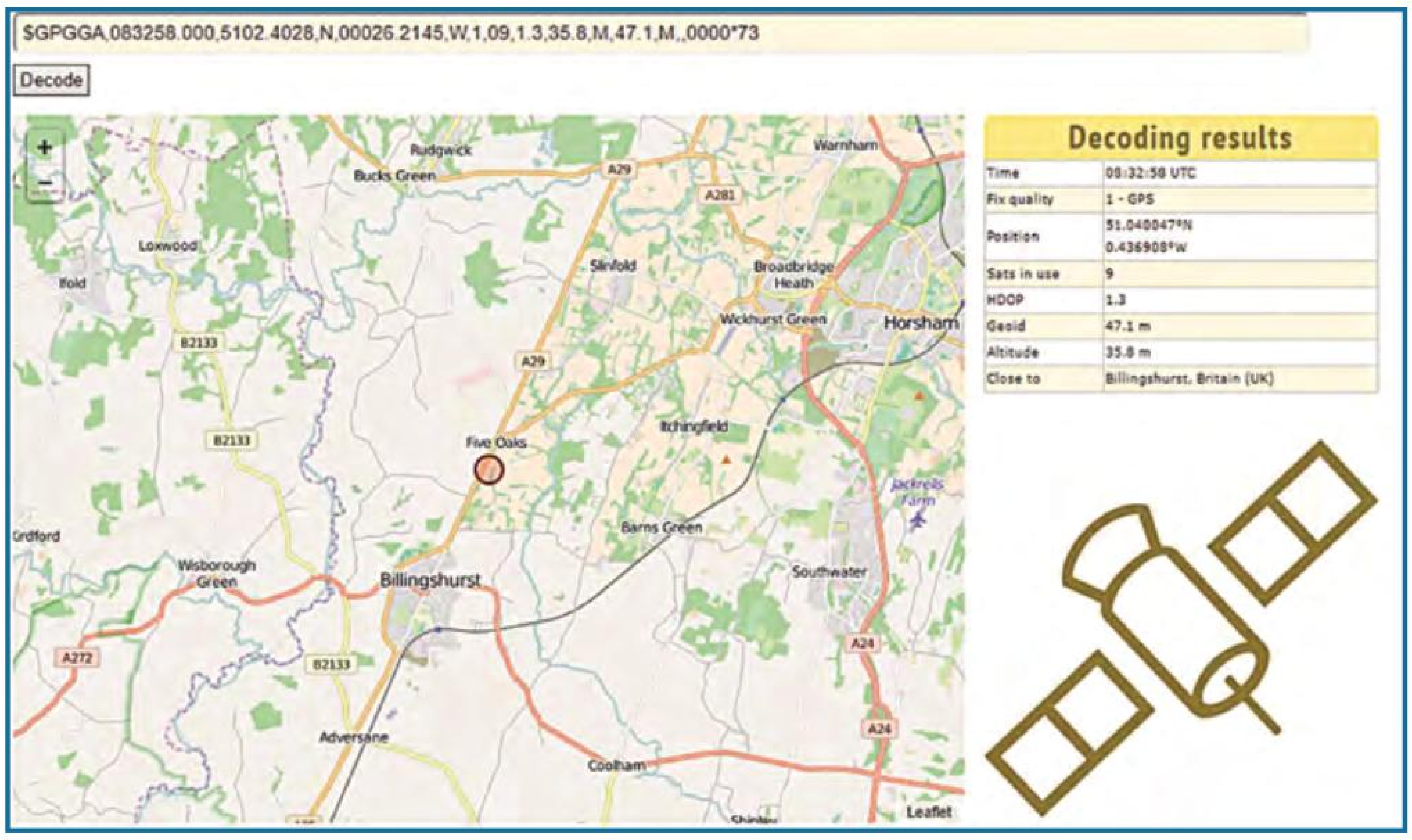
I/O pins (DIO0-DIO7) on the Arduino. This arrangement makes it possible to connect several GPS receivers simultaneously using different serial I/O connections.

An alternative lower-cost solution is shown in Fig.11.3. This takes the form of an external GPS module. As with the GPS shield, this uses a standard serial connection to the Arduino. The module is based on a u-blox NEO-6M GY-GPS6MV2 GPS receiver chip and matching antenna measuring a mere 25mm square. However, unlike the antenna shown in Fig.11.1, this one does not have a magnetic base and so will require mounting on an external surface with a clear and unobstructed view of the sky.

GPS

The global positioning system (GPS) was originally developed for use by the US military using satellites launched in 1978. Then referred to as 'Navstar' (navigation system with timing and ranging) the full constellation of satellites was not in place and operating until 1994. GPS is now widely available for use in many applications, including ship, ground-based vehicle and aircraft navigation.

GPS works by triangulating the distances from a number of satellites. A minimum of three satellites is required for a GPS receiver to calculate a unique lateral position, while four or more satellites provides additional altitude information (ie, a three-dimensional position fix). GPS requires a highly accurate time reference that's provided by means of atomic clocks in the GPS ground control stations and also in the GPS satellites themselves. Furthermore, because of its global accessibility, GPS has now become extremely popular as a provider of highly accurate time information.



```
$GPGGA,083258.000,5102.4028,N,00026.2145,W,1,09,1.3,35.8,M,47.1,M,,0000*73
```

Decoding results

Time	08:32:58 UTC
Fix quality	1 - GPS
Position	51.040047°N 0.436908°W
Sats in use	9
HDOP	1.3
Geoid	47.1 m
Altitude	35.8 m
Close to	Billingshurst, Britain (UK)

Fig.11.4. Using the on-line GPRMC and GPGGA decoder from Robert Larsson

GPS data

The data continuously transmitted by a GPS satellite is sent in the form of a series of ASCII characters. These characters are arranged in a format defined by the National Marine Electronics Association and so they are referred to as 'NMEA sentences'. Several different types of NMEA sentence are transmitted by satellites. The use of standard ASCII characters makes it possible to transmit GPS data using any common type of interface, such as serial RS-232, USB, Bluetooth, and Wi-Fi.

Extracting GPS data

Since not all of the received NMEA sentences will be relevant in a particular application and we will usually need to ignore those that we are not interested in and just concentrate on the sentences containing the data that we actually need. To do this, we first need to recognise the type of sentence before decoding the string of data contained in it. This is achieved using code that parses the data into meaningful chunks. Luckily, we don't need to write our own code to do this because there are some excellent libraries available to perform this task for us.

GPGGA and GPRMC

For most positioning applications the two most commonly used NMEA sentences are GPGGA and GPRMC (see Table 11.1). These carry GPS fix data and time, date, position, course and speed data respectively. Note that in some more complex GPS equipment GPGGA is replaced by GNGGA, which includes navigation data from multiple global navigation satellite sources (often both GPS and GLONASS satellites). A more complete list of NMEA output messages is shown in Table 11.1. If this is beginning to sound baffling because you are a newcomer to GPS operation we've included a glossary of the terms that you might be unfamiliar with on page 39.

Sentence type	Information content
GPGGA	Time, position and fix type data
GPGLL	Latitude, longitude, UTC time of position fix and status
GPGSA	GPS receiver operating mode, satellites used in the position solution and DOP values
GPGSV	Number of GPS satellites in view, satellite ID numbers, elevation, azimuth and signal-to-noise ratio (SNR) values
GPMSS	Signal-to-noise ratio, signal strength, frequency and bit rate from a radio-beacon receiver
GPRMC	Time, date, position, course and speed data
GPVTG	Course and speed information relative to the ground
GPZDA	PPS timing message (synchronized to PPS)

Table 11.1 NMEA messages

Parsing a typical NMEA sentence

Here's an example of a typical NMEA GPGGA sentence: `$GPGGA,083258.000,5101.4028,N,00026.9145,W,1,09,1.3,35.8,M,47.1,M,,0000*7B`

Let's parse this into some useful data. The first thing we should notice is that the sentence header (`$GPGGA`) tells us that this sentence contains time, position and fix data. From this data we can extract latitude and longitude as well as a variety of other useful data shown in Table 11.2.

If you need to parse a sentence you can always use an on-line service to decode the NMEA sentence. One of the best parsers available is at **http://rl.se/gprmc** (see Fig.11.4).

Errors, accuracy and precision

Several sources of error can be present in a GPS fix. Some errors can be introduced by signals received from multiple paths resulting from reflections from buildings and other large structures, as well as natural objects such as cliffs and rocky outcrops. Others can be caused by unwanted ionospheric and tropospheric effects. All of these factors can affect the time taken for satellite signals to arrive at a GPS receiver.

The combination of errors introduced when the GPS receiver calculates a position are expressed in terms of 'dilution of precision' (DOP). The DOP depends on the positions of the GPS satellites relative to the location of the GPS unit. Since the position of the received satellites is known it is possible to estimate the accuracy of a GPS position fix. The DOP calculation uses both the position and number of satellites available. However, since Navstar satellites constantly change position their number and position vary and so the DOP will change.

To make things a little more complicated, the DOP can be divided into vertical and horizontal components (VDOP and HDOP respectively). Lower values of VDOP and HDOP are associated with more accurate indications. For land and sea-based operation, HDOP is usually more important.

The important conclusion from all of this is that DOP provides you with a valuable indicator of how much confidence you can place on a particular GPS location fix. With lower DOP values your results are likely to be much better than when higher values of DOP are prevalent. You can reduce DOP and improve a GPS unit's positional accuracy by any one or more of the following:

1. Placing the antenna of your GPS receiver (or the complete GPS unit if it uses an integrated on-board patch or chip antenna) so that it benefits from a clear and unobstructed view of the full sky. This helps to increase the number of satellites in view and ensures that you are able to benefit from the most favourable satellite geometry.
2. Arranging the antenna of your GPS unit so that it is not susceptible to signals reflected from buildings, aircraft and other large structures.
3. Let your GPS average positons over a long period of time (eg, several minutes). If you are unable to do this you can check on the DOP values returned by the GPS unit, placing more confidence on the data when lower values of HDOP (or VDOP) are indicated.

Table 11.2 Example of data contained in a typical NMEA sentence

Name	Value	Format/units	Description
Message ID	$GPGGA		GGA protocol header
Time (UTC)	083258.000	hhmmss.sss	
Latitude	5101.4028	ddmm.mmmm	
N/S Indicator	N	N = north, S = south	
Longitude	00026.9145	ddmm.mmmm	
E/W indicator	W	E = east, W = west	
Position Fix Indicator	1	eg, 0 = Fix not available or invalid; 1 = GPS (SPS mode) fix valid; 2 = Differential GPS (SPS mode) fix valid	
Satellites used	9.0	0 to 12	
HDOP	1.3		Horizontal dilution of precision
Altitude (relative to mean sea level)	35.8	metres	
Units	M	metres	
Geoid separation	47.1	metres	
Units	M	metres	
Age of diff. corr.	0	second	Null fields when DGPS is not used
Diff. ref. Station ID	0000		
Checksum	*7B		Check for errors
Terminator	<CR><LF>		End of message termination

Coding Quickstart: Using the TinyGPS library

The problem of converting NMEA-format GPS data into variables that you can use with your Arduino code is handled very capably by Mikal Hart's excellent TinyGPS and Tiny GPS++ libraries. Not only does the library package handle the parsing and conversion of NMEA data, but it also includes several useful methods and functions that will allow you to process and present data in different ways.

Basic Usage

First you need to remember to include the TinyGPS library and then create a TinyGPS object, giving it a name of your choice. Note that, while it is possible to create multiple TinyGPS objects you will probably not need to make use of this facility and a single TinyGPS object will suffice for most applications. To create a TinyGPS object you must first include the TinyGPS library and then name the TinyGPS object:

```
#include "TinyGPS.h"
TinyGPS gps;
```

Each byte present within a received NMEA sentence is handled by the TinyGPS `encode()` method. To do this we can use the Arduino's SoftwareSerial library to obtain data from the GPS module – one character at a time. We continue with this process as long as valid data is available. This can be achieved using code of the form:

```
#include <SoftwareSerial.h>
#define RXPIN 3
#define TXPIN 2
#include "TinyGPS.h"

TinyGPS gps;
SoftwareSerial nss(RXPIN, TXPIN);

void loop()
{
  while (nss.available())
  {
    int c = nss.read();
    if (gps.encode(c))  // Valid?
    {
      // New GPS data processed here
    }
  }
}
```

Note, we have included the SoftwareSerial library because we will be using a pseudo-serial interface to connect the GPS module to the Arduino. In the previous block of code, we used digital I/O pin-2 and pin-3 for TX and RX respectively.

To obtain a simple position fix you can use code of the form:

```
gps.get_position(&latitude,
&longitude, &age)
```

Here, latitude and longitude are variables of long type, and the values are multiplied by 10,000. The age variable must be unsigned long type. Alternatively, it is possible to use float-type variables using the following line of code:

```
gps.f_get_position(&flatitude,
&flongitude, &age)
```

Here, latitude and longitude are float variables and the actual values are returned (ie, not multiplied by 10,000). Note that, while float-type variables are easier to use they produce slower and somewhat larger code. As before, the age variable must be unsigned long type.

```
gps.get_datetime(&date,
&time, &age);
```

```
gps.crack_datetime(&year,
&month, &day, &hour,
&minute, &second,
&hundredths, &age);
```

Table 11.3 summarises some of the

in-line functions available for use with the TinyGPS library.

Statistics

The `stats()` method provides you with a means of checking that the received GPS data is reliable, for example:

```
gps.stats(&chars, &sentences,
&failed
```

Displays the number of characters fed to the GPS object, as well as the number of valid $GPGGA and $GPRMC sentences processed and also indicates the number of sentences that fail the checksum test.

Method	Use
`gps.f_altitude()`	Returns the altitude in metres
`gps.course()`	Returns course in 100ths of a degree
`gps.speed()`	Returns speed in 100ths of a knot
`gps.f_course()`	Returns speed in m/s as a float type
`gps.f_speed_knots()`	Returns speed in knots as a float type
`gps.f_speed_mph()`	Returns speed in miles / hr as a float type
`gps.f_speed_kmph()`	Returns speed in km/hr as a float type
`gps.f_speed_mps()`	Returns speed in m/s as a float type

Table 11.3 Some of the in-line functions methods available for use with the TinyGPS library

GPS glossary

American Standard Code for Information Interchange (ASCII)

ASCII is the most commonly used standard for sending and receiving electronic data. ASCII is based on alphanumeric characters (letters and numbers), punctuation and some basic control characters. Basic ASCII uses 7-bits of data to represent a single character, while extended ASCII uses a single byte (8-bits) to transmit each character.

Antenna

GPS receivers require an antenna in order to collect signals transmitted by GPS satellites. Since the wavelength is relatively short (approximately 20cm) antennas can be quite compact. Some GPS patch antennas can be as small as 1.5cm-square. Patch antennas are ideal for situations where the antenna is mounted on a flat surface; eg, the roof or dashboard of a car. When mounted on a large ground plane (eg, a car roof), patch antennas can exhibit relatively large values of gain. This, coupled with their relatively low profile, makes them highly appropriate for use in vehicle and aircraft applications. Small, printed-circuit-mounted chip antennas are also becoming popular for use in low-cost applications where space is paramount. Helical antennas are also found on some equipment. They are particularly suitable for use in applications where orientation is unpredictable or when a robust external antenna is needed.

Augmentation system

To improve the accuracy and resolution of GPS systems a network of ground based stations send correction data back to GPS satellites. Such systems include the Wide Area Augmentation System (WAAS) in North America and EGNOS (European Geostationary Navigation Overlay Service) in Europe.

Bit rate

GPS units invariably use a serial data interface to transfer information to a computer or microcontroller. While this data is often sent at a bit rate of 9600 bits per second, higher speeds are becoming increasingly common.

Chipsets

GPS units employ a particular manufacturer's chipset to provide all of the required GPS functions (including RF amplification, signal processing, correlation, power control, interfacing, and so on). Manufacturers of popular GPS chipsets include SiRF, Broadcom, u-blox and Navika.

Constellation

GPS satellites circle the earth in medium Earth orbit (MEO) at an altitude of approximately 20,200km (12,550 miles). The baseline satellite constellation consists of 24 satellites arranged in six earth-centered orbital planes. The system can support a constellation of up to thirty satellites in orbit for increased reliability. The satellites in the GPS constellation are arranged into six equally-spaced orbital planes comprising four slots. This ensures that GPS receivers are always within view of at least four of the baseline satellites.

Correlators and channels

Each of the signals transmitted by different GPS satellites has a pseudo-random code comprising a sequence of 1023 binary 1s and 0s. These sequences are modulated using binary phase-shift keying (BPSK). The resulting modulated signal occupies a significant amount of spectrum space and a GPS receiver employs a circuit known as a 'correlator' to recover the original narrowband data from the received signal. In practice, several correlators can be present and operating at the same time and this can significantly reduce the TTFF with different correlators operating on signals from different satellites. In effect, each of these correlators can be considered to be acting on a different information 'channel'. Modern GPS units can use as many as 50 different channels, though typically no more than about a dozen or so will actually be in use at any time.

Differential GPS (DGPS)

DGPS units incorporate additional antenna input and RF signal processing that allows them to receive signals directly from ground stations as well as signals from GPS satellites. DGPS receivers provide significantly enhanced accuracy when compared with standard GPS receivers.

Ephemeris

Ephemeris is transient data transmitted by GPS satellites that provides information about their current (and predicted) location, timing and status. Ephemeris data can be used to predict future satellite conditions at a specified location/time.

Lock

A GPS receiver normally requires four or more satellites in view to accurately fix a position. In this condition the receiver is said to be 'locked'. Note that multiple satellites are required in order to provide accurate position and time information.

Start-up time

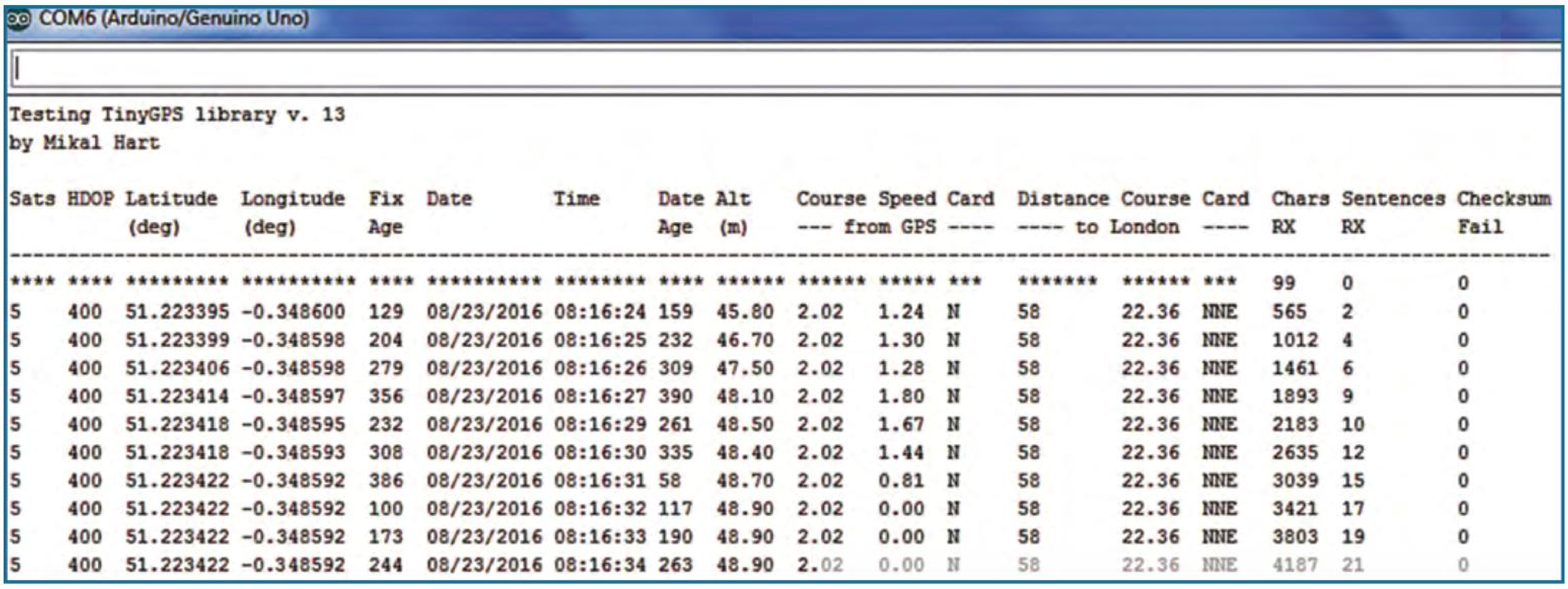
Different startup times are usually quoted for GPS units, depending on whether they are started from cold, warm or hot. A cold start refers to a restart of a unit after a long period of time with no voltage supplied from a backup battery or capacitor. A warm start assumes that ephemeris data is still present and available. A hot start assumes that the previously received satellite constellation is unchanged and that lock can be obtained in the fastest possible time. Like TTFF, start-up time is another key performance indicator.

Time-to-first fix (TTFF)

The time taken to obtain an initial position fix is a measure of how long you will need to wait for the unit to return latitude, longitude and other data. It is a key performance indicator of a GPS unit. Since a GPS unit needs to receive signals from as many satellites as possible, the TTFF can be significantly degraded when a GPS unit is not optimally positioned or when it is used in a difficult location (for example, in a ground-floor room).

Update Rate

A GPS unit will try to fix location on a continuous basis. The rate it does this is called the 'update rate'. The standard for most GPS modules is one update per second (1Hz). This is adequate for a large number of applications, but faster rates are essential for applications involving aircraft and other fast-moving vehicles). Low-cost GPS equipment supporting faster update rates (eg, 5Hz and 10Hz) is becoming increasingly common. Note that these increased update rates require faster processing of NMEA sentences.



```
Testing TinyGPS library v. 13
by Mikal Hart

Sats HDOP Latitude  Longitude  Fix  Date       Time     Date Alt    Course Speed Card  Distance Course Card  Chars Sentences Checksum
          (deg)     (deg)      Age                      Age  (m)    --- from GPS ----  ---- to London  ----  RX    RX        Fail
-------------------------------------------------------------------------------------------------------------------------------------
**** **** ********* ********** **** ********** ******** **** ****** ****** ***** ***   ******* ****** ***   99    0         0
5    400  51.223395 -0.348600  129  08/23/2016 08:16:24 159  45.80  2.02   1.24  N     58       22.36  NNE   565   2         0
5    400  51.223399 -0.348598  204  08/23/2016 08:16:25 232  46.70  2.02   1.30  N     58       22.36  NNE   1012  4         0
5    400  51.223406 -0.348598  279  08/23/2016 08:16:26 309  47.50  2.02   1.28  N     58       22.36  NNE   1461  6         0
5    400  51.223414 -0.348597  356  08/23/2016 08:16:27 390  48.10  2.02   1.80  N     58       22.36  NNE   1893  9         0
5    400  51.223418 -0.348595  232  08/23/2016 08:16:29 261  48.50  2.02   1.67  N     58       22.36  NNE   2183  10        0
5    400  51.223418 -0.348593  308  08/23/2016 08:16:30 335  48.40  2.02   1.44  N     58       22.36  NNE   2635  12        0
5    400  51.223422 -0.348592  386  08/23/2016 08:16:31 58   48.70  2.02   0.81  N     58       22.36  NNE   3039  15        0
5    400  51.223422 -0.348592  100  08/23/2016 08:16:32 117  48.90  2.02   0.00  N     58       22.36  NNE   3421  17        0
5    400  51.223422 -0.348592  173  08/23/2016 08:16:33 190  48.90  2.02   0.00  N     58       22.36  NNE   3803  19        0
5    400  51.223422 -0.348592  244  08/23/2016 08:16:34 263  48.90  2.02   0.00  N     58       22.36  NNE   4187  21        0
```

Fig.11.5. GPS data displayed using the Arduino IDE's Serial Monitor and example code supplied with the TinyGPS library

Installing the TinyGPS library

The TinyGPS library is not shipped as part of the Arduino IDE package – you'll need to install it using the IDE's Library Manager. First, download the library in a zipped file from **http://arduiniana.org/libraries/tinygps**. When you have located the latest version (currently version 1.3) you can click to download the zipped file to your computer.

Next, from within the Arduino IDE select 'Sketch', 'Include Library' and 'Add .ZIP library' then locate the downloaded zip file and click to 'Open' it. You should now find that TinyGPS appears in your list of 'Contributed Libraries', allowing you to successfully compile Arduino code that uses the TinyGPS library. The library is currently shipped with three example programs (they will appear under 'Examples' in your IDE). These are contained within folders labelled **simple_test**, **static_test**, and **test_with_gps_device**. These examples can be loaded into the IDE (as **.INO** files) and then compiled before uploading to your own Arduino. It is well worth spending a little time getting familiar with each of the examples before attempting to write your own code (see Fig.11.5).

Arduino Workshop: Using GPS modules

GPS modules require a serial interface, conventionally running at 9,600 bps. This interface can use any of the (appropriately configured) digital I/O lines. In most applications you might need to include the following libraries:

```
#include <LCD.h>                // If using CD display
#include <LiquidCrystal_I2C.h> // If using serial I2C interface
#include <SoftwareSerial.h>    // Needed for LCD interface
#include <TinyGPS.h>            // The TinyGPS library
```

The following fragments of code will give you an idea of how data from a GPS module can be obtained within your own code. First, display the number of satellites being received using the IDE's serial monitor:

```
Serial.print("Satellites: ");
Serial.println(gps.satellites());
```

Display the number of satellites being received on an LCD display:

```
lcd.print("Satellites: ");
lcd.print(gps.satellites());
```

Display the HDOP using the serial monitor:

```
Serial.print("HDOP: ");
Serial.println(gps.hdop());
```

Display the HDOP on an LCD display:

```
lcd.print("HDOP: ");
lcd.print(gps.hdop());
```

Display the number of characters and sentences received using the IDE's serial monitor:

```
 // First we need to get the statistics to display
   unsigned long chars = 0;
   unsigned short sentences = 0, failed = 0;
   gps.stats(&chars, &sentences, &failed);
   // Then we can send them to the serial monitor
   Serial.print("Characters: ");
   Serial.println(chars);
   Serial.print("Sentences: ");
   Serial.println(sentences);
```

Display the number of characters and sentences received on an LCD display:

```
// First we need to get the statistics
unsigned long chars = 0;
unsigned short sentences = 0, failed = 0;
gps.stats(&chars, &sentences, &failed);
// Send number of characters to first
// line of the LCD display
lcd.setCursor(0,0);
lcd.print("Characters: ");
lcd.print(chars);
// Send number of sentences to second
// line of the LCD display
lcd.setCursor(0,1);
lcd.print("Sentences: ");
lcd.print(sentences);
```

More advanced features

The TinyGPS library incorporates some useful advanced features, such as an ability to compute the distance and heading of one location from another (see Fig.11.5). For example:

```
TinyGPS::distance_between (lat1,
long1, lat2, long2)
```

This returns the distance in meters between two positions where both are specified as signed decimal degrees of latitude and longitude. Next we have:

```
TinyGPS::course_to (lat1, long1,
lat2, long2)
```

This returns the course in degrees (North = 0°, West = 270°) from the first to the second position where both are specified as signed decimal degrees of latitude and longitude. If one of the two locations is obtained from `gps.get_position()` or `gps.fget_position()` it is possible to compute and display the distance and bearing from a fixed point of reference, such as your home or destination. This point of reference could be defined as a constant in your code, using code of the form: `static const double LONDON_LAT = 51.508131, LONDON_LON = -0.128002;`

For further information on how this is done take a look at: `test_with_gps_device.ino` which, as mentioned earlier, is included in the folder of examples currently shipped with the TinyGPS library.

Get Real : Arduino proximity warning system

In this month's *Get Real* we will be using an Arduino Uno in conjunction with a low-cost GPS receiver module. The module is available from a number of suppliers and based on a popular u-blox NEO-6M GY-GPS6MV2 GPS chipset with on board electrical-erasable memory (EEPROM), power supply regulator and a matching antenna. The module is frequently used in model aircraft applications and is often supplied with a 4-way male header that can be soldered in place.

You will need

Arduino Uno
u-blox Neo-6M GY-GPS6MV2 GPS receiver module with matching patch antenna
Connecting leads
USB cable with USB connector (for programming only)
Computer with an available powered USB port (for programming only)
20 character × 4-line LCD display with I^2C interface (see text)
Single-pole single-throw (SPST) switch, S1
9V battery, B1

LCD display interface

The 20-character, 4-line display used in this project can be obtained from various sources. However, to minimise the wiring and avoid having to use multiple digital I/O lines we have interfaced the display to the Arduino Uno using a

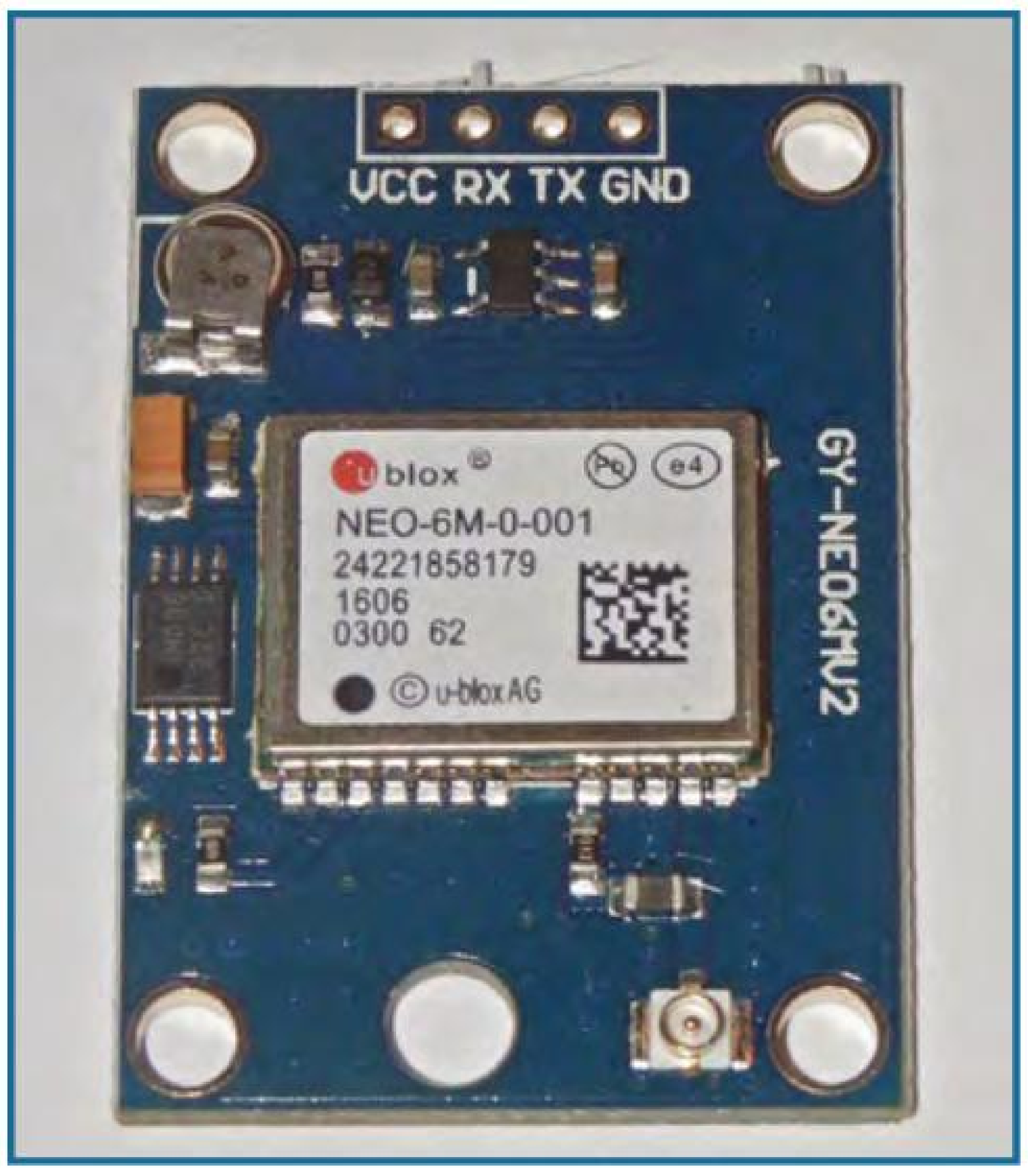


Fig.11.6. The u-blox Neo-6M GY-GPS6MV2 GPS module

Table 11.4 u-blox GY-GPSD6MV2 GPS specification

Parameter	Specification
Supply voltage range	3.3-6V (on board voltage regulator provides 3.3V to receiver)
Supply current	35 mA (11mA in power saving mode)
I/O maximum logic level	3.6V (a logic level converter is required for interfacing with a standard PC or other 5V logic-compatible microcontrollers)
Recommended baud rate	9600 bps (UART configurable from 4800 to 115200 baud)
Operating frequency	1.57542GHz
Sensitivity	–156dBm (hot-start)
Time to first fix (TTFF)	Typically less than 1s for a hot-start and 27s for a cold-start
Update RATE	10Hz maximum (1Hz default)
Number of channels supported	50
Maximum update rate	5Hz (1Hz typical)
Positional accuracy	2m (or better) achievable
Typical velocity accuracy	0.1m/s
Maximum velocity	500m/s
Heading accuracy	0.5° achievable while in motion
Memory	Battery backed EEPROM

Listing 11.1 Complete code listing for the Arduino GPS location fix

```
// Simple Arduino GPS location fix
// Include the necessary libraries
#include <LCD.h>
#include <LiquidCrystal_I2C.h>
#include <SoftwareSerial.h>
#include <TinyGPS.h>

// *** LCD display settings ***
#define I2C_ADDR 0x27 // <<----- change if necessary
#define BACKLIGHT_PIN 3
#define En_pin 2
#define Rw_pin 1
#define Rs_pin 0
#define D4_pin 4
#define D5_pin 5
#define D6_pin 6
#define D7_pin 7
#define bl 3
#define blpol POSITIVE
LiquidCrystal_I2C lcd(I2C_ADDR,En_pin,Rw_pin,Rs_pin,D4_pin,D5_
pin,D6_pin,D7_pin,bl,blpol);

// Define the Arduino pins used for serial GPS interface
#define RXPIN 10
#define TXPIN 11

// Create an instance of the TinyGPS object
TinyGPS gps;
SoftwareSerial ss(RXPIN, TXPIN);

void setup()
{
  ss.begin(9600);          // GPS serial bit rate
  lcd.begin (20,4);        // 20 characters x 4 lines
  lcd.setBacklight(HIGH);
}

void loop()
{
  bool newData = false;
  unsigned long chars;
```

Listing 11.1 continued on next page

compatible I^{2}C interface. The interface is often supplied together with the display and either already soldered in place or supplied with a suitable header for interconnection. Note that the I^{2}C interface is attached to the rear of the LCD display, as shown in Fig.11.9.

Code

The complete code listing for the GPS location fixer is shown in Listing 11.1. Before finalising your code, you will need to determine the I^{2}C address of your display. Often this will be `0x27` (ie, hexadecimal 27) but you can check this by running the Arduino's I^{2}C Scanner application, as shown in Fig.11.10. The I^{2}C Scanner is available from: **http://playground.arduino.cc/Main/I2cScanner**. If you need statistical data in order to check the operation of your Arduino-based location fixer you can make use of the code in Listing 11.2. The source code for both of our applications can be downloaded from the *EPE* website: **www.epemag3.com**

Note that both of our applications require the following libraries: `LCD.h`, `LiquidCrystal_I2C.h`, `SoftwareSerial.h` and `TinyGPS.h`. Finally, and since there are several LCD libraries in existence, it is important to ensure that you use the correct library for the particular LCD that you use. In many cases guidance and web-links are provided by suppliers, but it is well worth double checking that you are using the correct library for your particular display.

Testing and adjustment

As with our previous *Get Real* projects, your code should first be entered into the IDE and then saved before compiling and uploading it to the Uno, as described previously in Arduino Workshop. When you have debugged and corrected your code don't forget to save it by clicking on 'File' and 'Save' or 'Save As…'. Finally, click on 'Sketch' and 'Verify/Compile'. Any compilation errors will then be reported in the window at the bottom of the IDE.

When you've corrected any coding errors that the compiler reports you will be ready to upload your code to the Uno. Just click on the upload arrow and watch the progress report. After the Uno performs a reset the LCD display will remain blank until the GPS module is reporting data. This may take several minutes from a cold start and up to a minute following a hot start. Note that, when the u-blox GPS module is powered it will automatically acquire satellite signals and a position fix. Once the unit has acquired a position fix the module will blink the on board LED and the LCD should display information – see Fig.11.11 and Fig.11.12, which respectively show the results of running

Listing 11.1 continued

```
  unsigned short sentences, failed;
  // Parse GPS data for 2 seconds
  for (unsigned long start = millis(); millis() - start < 2000;)
  {
    while (ss.available())
    {
      char c = ss.read();
      if (gps.encode(c)) // Is the sentence valid?
        newData = true;
    }
  }

  if (newData)
  {
    // Extract the GPS data from the received sentences
    float flat, flon;
    unsigned long age;
    gps.f_get_position(&flat, &flon, &age);
    int year;
    byte month, day, hour, minute, second, hundredths;
    gps.crack_datetime(&year, &month, &day, &hour, &minute,
&second,&hundredths);
    float falt = gps.f_altitude();
    // Send the data to the LCD panel
    // The first line will display the time
    lcd.clear();
    lcd.setCursor(0,0);
    lcd.print("Time = ");
    lcd.print(hour, DEC);
    lcd.print(":");
    lcd.print(minute, DEC);
    lcd.print(":");
    lcd.print(second, DEC);
    // The second line will display the latitude
    lcd.setCursor(0,1);
    lcd.print("Lat. = ");
    lcd.print(flat == TinyGPS::GPS_INVALID_F_ANGLE ? 0.0 : flat, 4);
    lcd.setCursor(0,2);
    // The third line will display the longitude
    lcd.print("Lon. = ");
    lcd.print(flat == TinyGPS::GPS_INVALID_F_ANGLE ? 0.0 : flon, 4);
    lcd.setCursor(0,3);
    // Fourth line will display altitude and number of satellites
    lcd.print("Alt. = ");
    lcd.print(falt);
    lcd.print("   *->");
    lcd.print(gps.satellites() == TinyGPS::GPS_INVALID_
SATELLITES ? 0 : gps.satellites());
  }
}
```

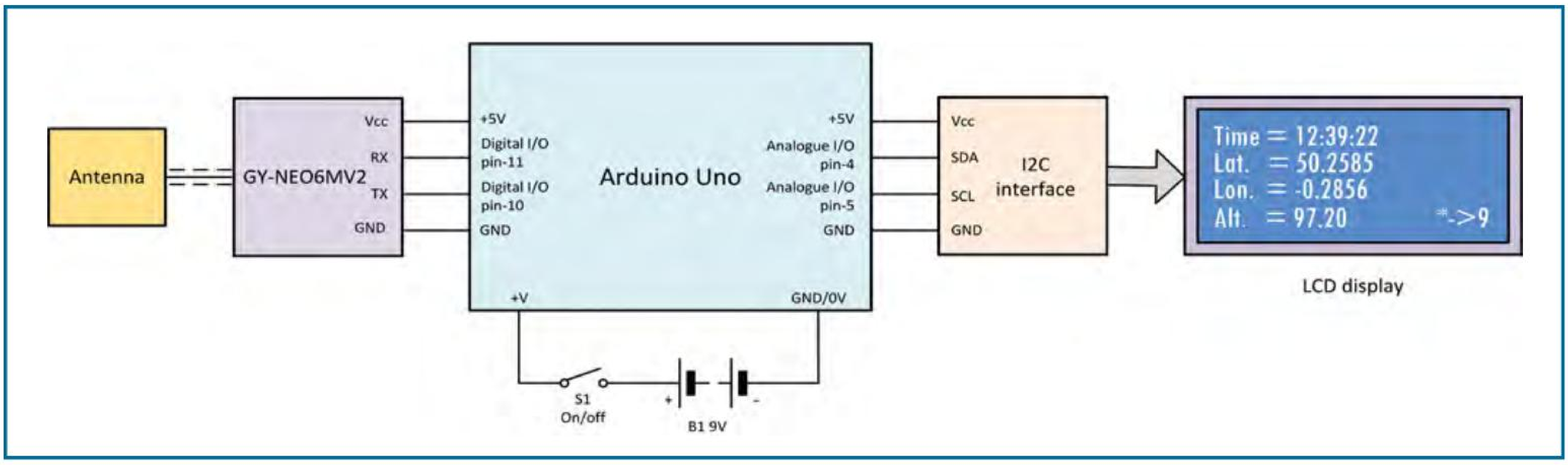


Fig.11.7. Complete circuit of the Arduino GPS fixer

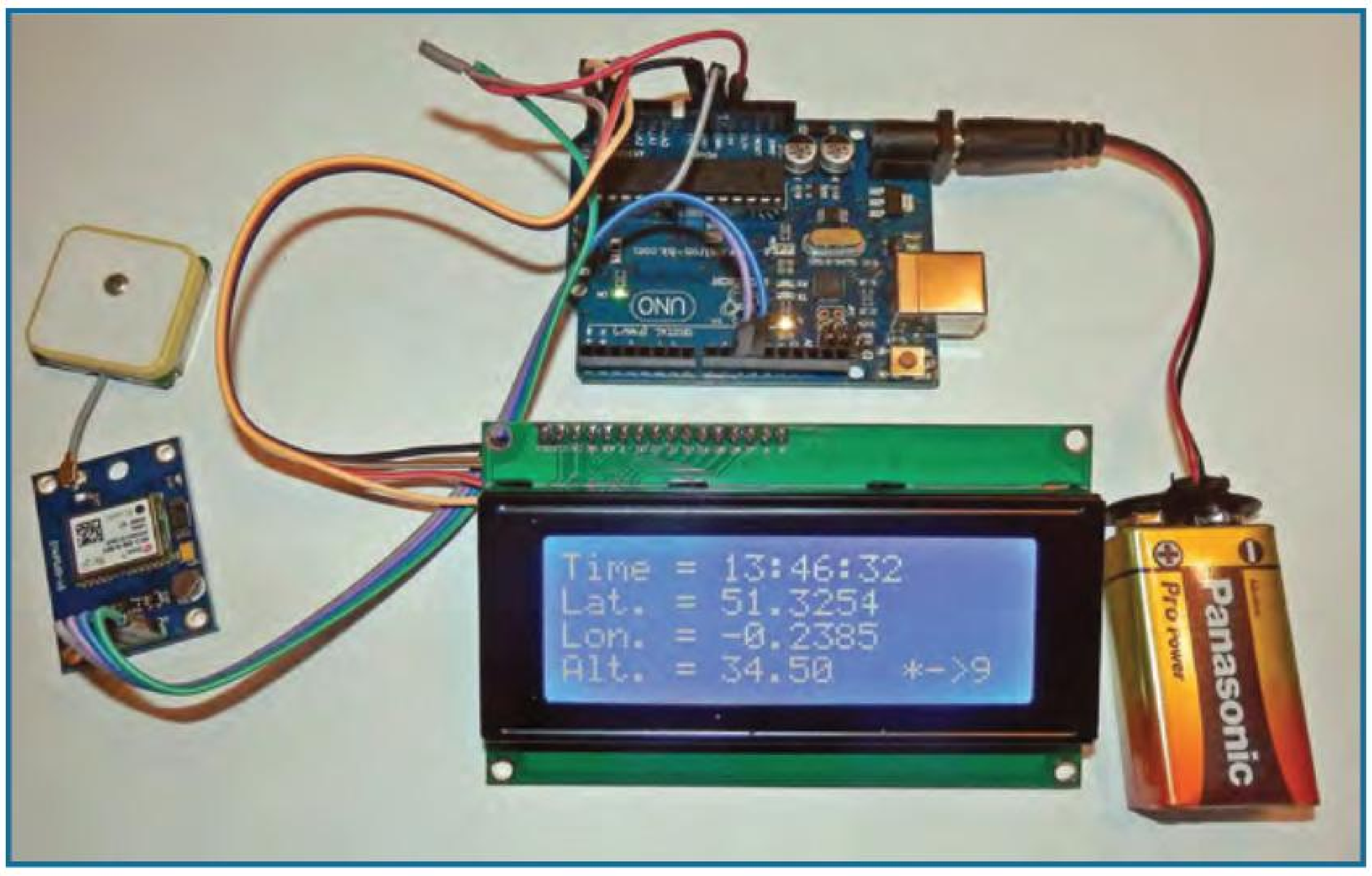
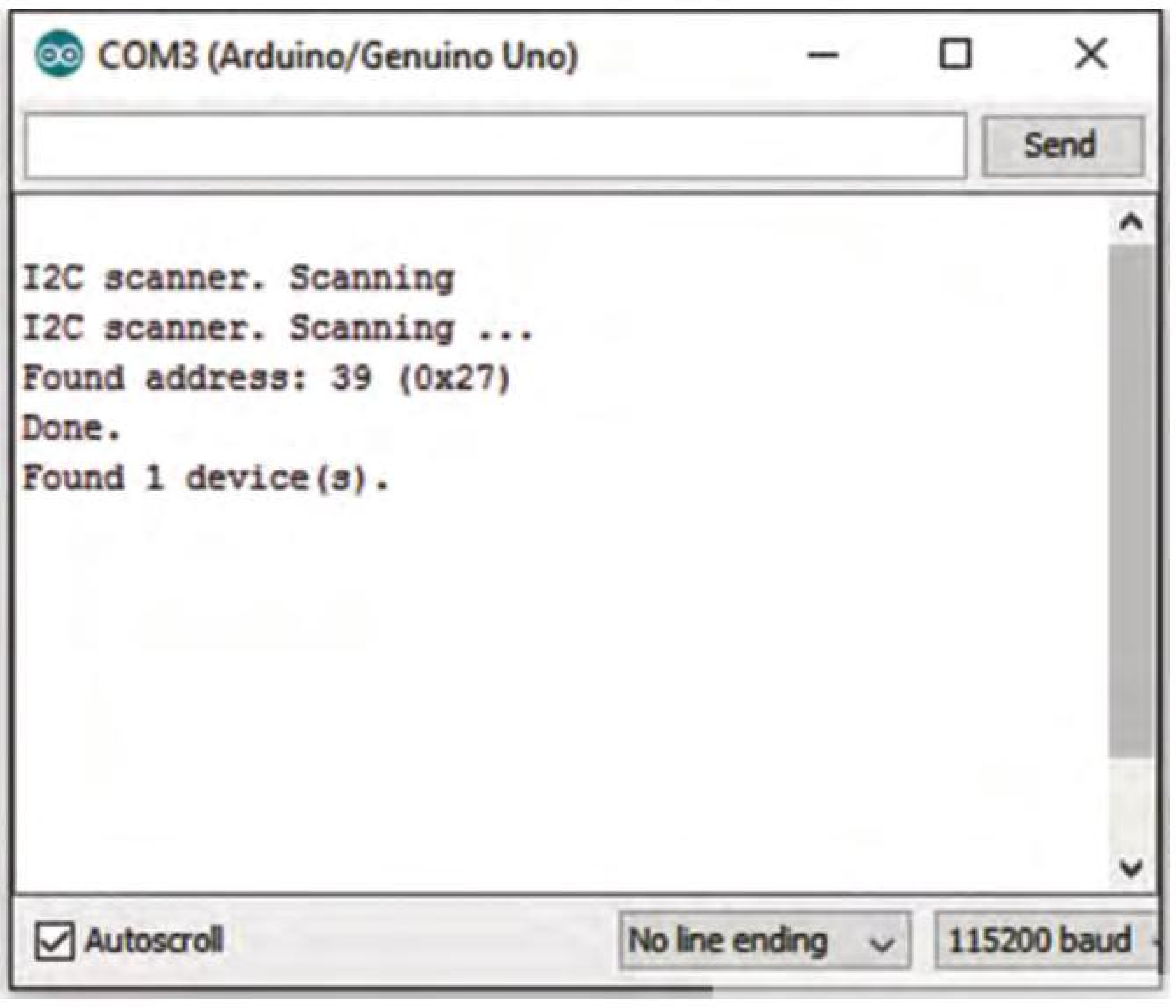

Time = 13:46:32
Lat. = 51.3254
Lon. = -0.2385
Alt. = 34.50 *->9
Panasonic
Pro power
UNO

Fig.11.8. The completed Arduino GPS location fixer


COM3 (Arduino/Genuino Uno)
Send
Autoscroll
No line ending
115200 baud

```
I2C scanner. Scanning
I2C scanner. Scanning ...
Found address: 39 (0x27)
Done.
Found 1 device(s).
```

☑ Autoscroll

Fig.11.10. Running the Arduino I^{2}C scanner

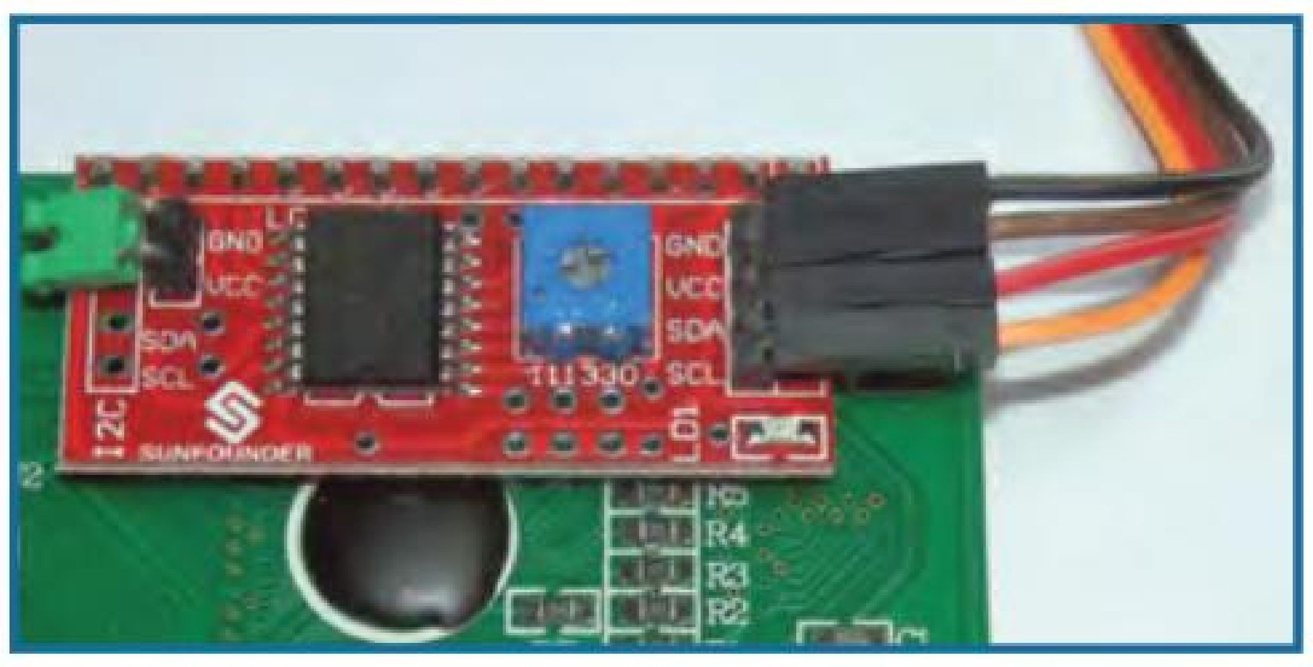

GND
VCC
SDA
SCL
SUNFOUNDER

Fig.11.9. I^{2}C interface connected to rear of the 20-character, 4-line display

the code shown in Listing 11.1 and 11.12 respectively.

Going further

As always, there's a great deal of scope for going further with this month's *Get Real* project. For example:

- Adding one or more push-button switches connected as inputs to the Uno so that different display screens can be cycled. For example, basic time and position information, altitude and speed, and statistics including number of satellites, HDOP and sentences received
- Adding a standard SD-card shield (see Fig.11.13) so that received location data, altitude and speed can be recorded in a data file for later analysis. This will add a basic tracking facility to your GPS location fixer. Alternatively, if you are using a ready-made GPS shield you may find

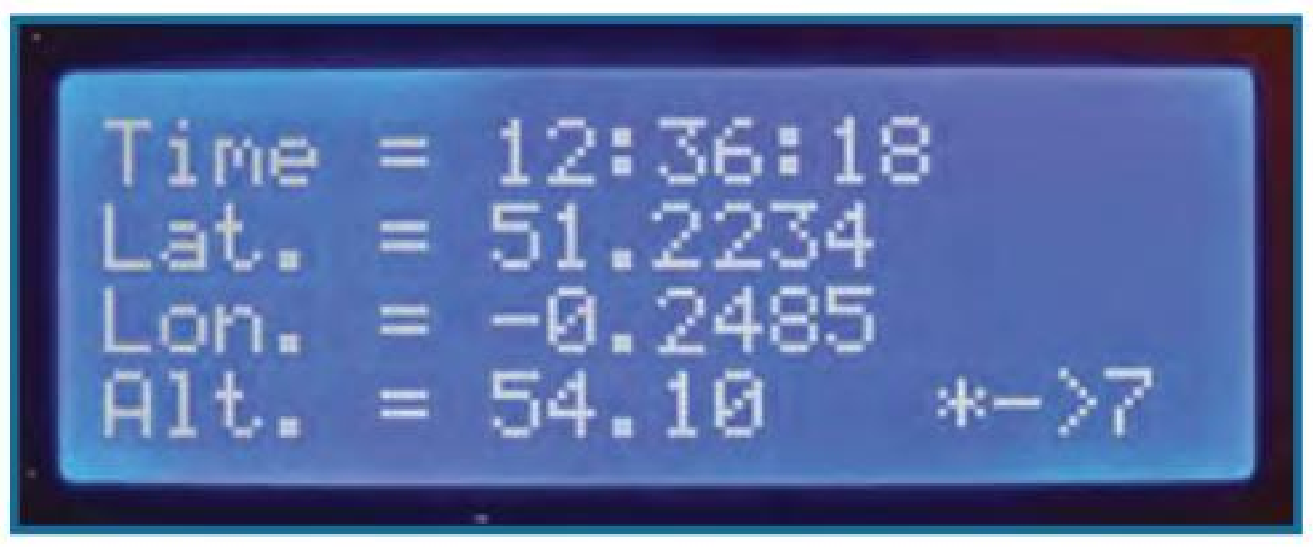

Time = 12:36:18
Lat. = 51.2234
Lon. = -0.2485
Alt. = 54.10 *->7

Fig.11.11. Time and position information provided on the LCD display of the GPS location fixer

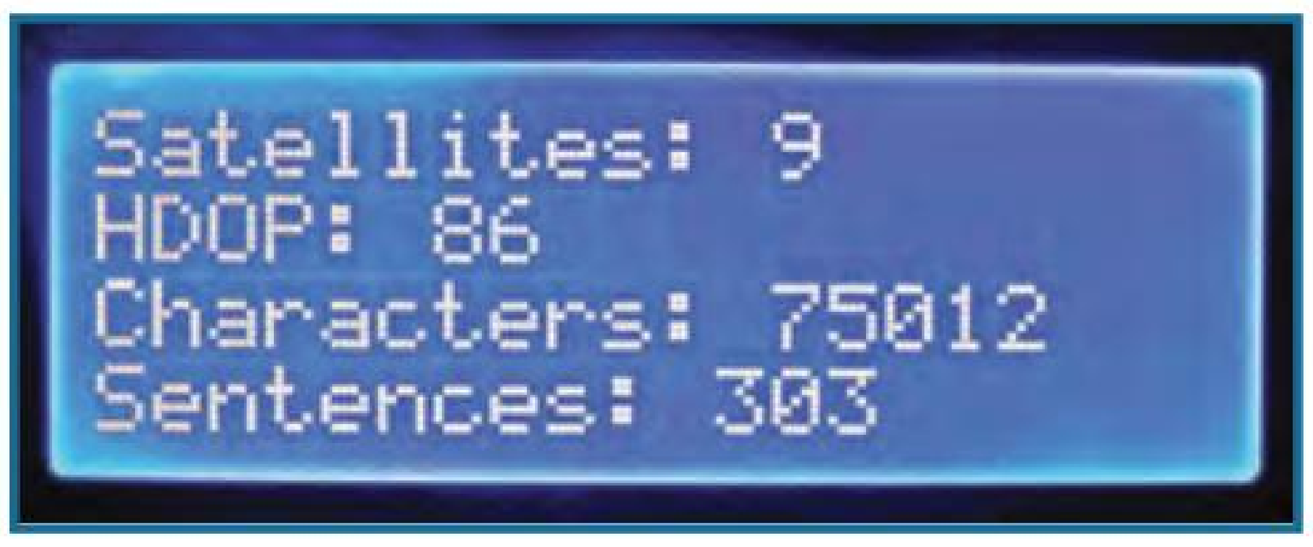

Satellites: 9
HDOP: 86
Characters: 75012
Sentences: 303

Fig.11.12. GPS statistical information displayed on the LCD display of the Arduino GPS location fixer

Listing 11.2 GPS statistical information display

```
// GPS information display
// Include the necessary libraries
#include <LCD.h>
#include <LiquidCrystal_I2C.h>
#include <SoftwareSerial.h>
#include <TinyGPS.h>

// *** LCD display settings ***
#define I2C_ADDR 0x27 // <<----- change if necessary
#define BACKLIGHT_PIN 3
#define En_pin 2
#define Rw_pin 1
#define Rs_pin 0
#define D4_pin 4
#define D5_pin 5
#define D6_pin 6
#define D7_pin 7
#define bl 3
#define blpol POSITIVE
LiquidCrystal_I2C lcd(I2C_ADDR,En_pin,Rw_pin,Rs_pin,D4_pin,D5_
pin,D6_pin,D7_pin,bl,blpol);

// Define the Arduino pins used for serial GPS interface
#define RXPIN 10
#define TXPIN 11

// Create an instance of the TinyGPS object
TinyGPS gps;
SoftwareSerial ss(RXPIN, TXPIN);

void setup()
{
  ss.begin(9600);          // GPS serial bit rate
  lcd.begin (20,4);        // 20 characters x 4 lines
  lcd.setBacklight(HIGH);
}

void loop()
{
  bool newData = false;
  unsigned long chars;
  unsigned short sentences, failed;

  // Parse GPS data for 2 seconds
  for (unsigned long start = millis(); millis() - start < 2000;)
  {
    while (ss.available())
    {
      char c = ss.read();
```

Listing 11.2 continued on next page

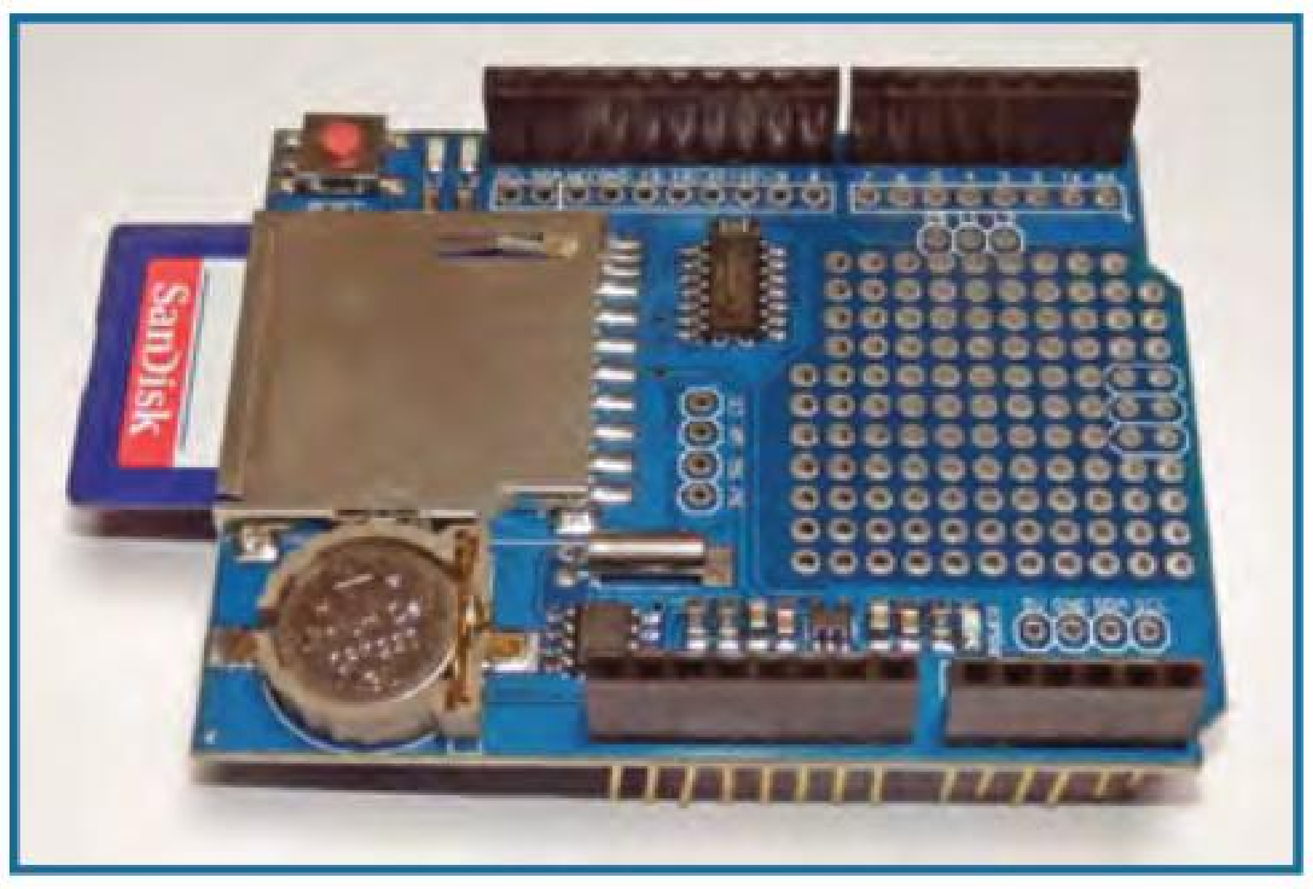


Fig.11.13. Standard SD card shield for the Arduino Uno can be used to store GPS tracking data

that the board already has a micro-SD card slot fitted (see Fig.11.14).

- Providing a means of displaying navigational information relative to a destination location (such as your home, place of work or intended destination). The TinyGPS library provides you with methods that will allow you to do this.

All of these additions could be easily incorporated into the basic Arduino code and they will provide you with a great opportunity to further develop your coding skills.

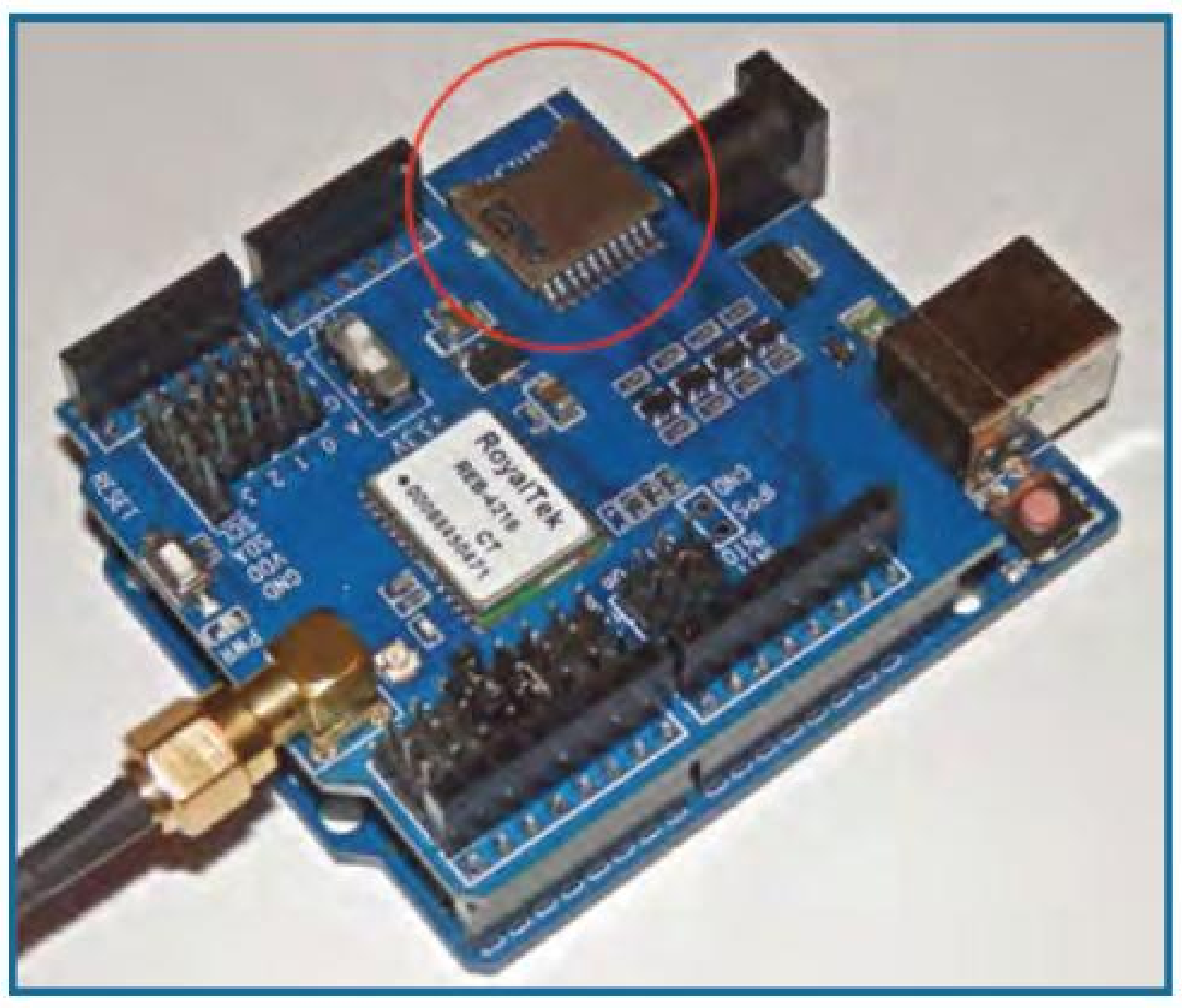


Fig.11.14. The micro-SD card slot fitted to a ready-made Arduino GPS shield provides another means of storing GPS data for tracking purposes

Next month

In next month's *Teach-In 2016, Arduino World* will be looking at wireless networking and the ESPduino microcontroller that combines Arduino compatibility with an ability to connect to a wireless network via an on-board ESP8266 wireless module. *Arduino Workshop* will introduce you to the extended I/O facilities offered by the Arduino Mega, while our programming feature, *Coding Quickstart* will show you how to get the best out of the ESP8266 wireless module. Our *Get Real* project will bring our current *Teach-In 2016* series to a conclusion by showing you how to get started with the Internet of Things (IoT).

Arduino Beginner?

These YouTube videos were designed to get your project off the ground!

http://bit.ly/arduinites

Listing 11.2 continued

```
      if (gps.encode(c)) // Is the sentence valid?
        newData = true;
    }
  }

  if (newData)
  {
    // Send the data to the LCD panel
    lcd.clear();
    // The first line will display the number of satellites in view
    lcd.setCursor(0,0);
    lcd.print("Satellites: ");
    lcd.print(gps.satellites());
    // The second line will display the HDOP
    lcd.setCursor(0,1);
    lcd.print("HDOP: ");
    lcd.print(gps.hdop());
    // Now get some statistics
    unsigned long chars = 0;
    unsigned short sentences = 0, failed = 0;
    gps.stats(&chars, &sentences, &failed);
    // The third line will display the characters received
    lcd.setCursor(0,2);
    lcd.print("Characters: ");
    lcd.print(chars);
    //
    // The fourth line will display the sentences received
    lcd.setCursor(0,3);
    lcd.print("Sentences: ");
    lcd.print(sentences);
   }
}
      char c = ss.read();
      if (gps.encode(c)) // Is the sentence valid?
        newData = true;
    }
  }

  if (newData)
  {
    // Extract the GPS data from the received sentences
    float flat, flon;
    unsigned long age;
    gps.f_get_position(&flat, &flon, &age);
    int year;
    byte month, day, hour, minute, second, hundredths;
    gps.crack_datetime(&year, &month, &day, &hour, &minute,
&second,&hundredths);
    float falt = gps.f_altitude();
    // Send the data to the LCD panel
    // The first line will display the time
    lcd.clear();
    lcd.setCursor(0,0);
    lcd.print("Time = ");
    lcd.print(hour, DEC);
    lcd.print(":");
```

Corrections – our thanks to readers who've reported errors in *Teach-In 2016*. Ian Spencer queried the code shown in Listing 8.3 (Sep 2016). Inside the main `loop()` of the code, the reference to `results.value == code[n]` should read `results.value == code[n-2]`. The code will then compile normally and each relay will correspond to the correct number on the remote control keypad. Note that keypad button '1' controls relay output Channel 1 and this has been mapped to the Arduino's DIO2 with the corresponding IR code stored in element 0 of the `code[]` array. (We decided to avoid using DIO0 and DIO1 so that they could be left available for serial communication (RX and TX respectively).

Walter King spotted an error in Table 9.1 (Oct 2016). This shows the Ethernet start of the frame delimiter as having a byte value of '1101010' – it should be '10101011' (hexadecimal D5). The SFD is the eight-bit (one-byte) value that marks the end of the preamble, which is the first field of the Ethernet packet data, marking the beginning of the Ethernet frame. The SFD provides a means of breaking the bit pattern of the preamble and signalling the start of the actual frame.

NET WORK

by Alan Winstanley

In the Echo chamber

AMAZON has been busy with the UK launch of its Amazon Echo device some two years after making its US debut. Echo has stolen the lead, and its new stand-alone 'smart speaker' is at the forefront of Wi-Fi-controlled devices that hook to a home network. The voice-activated cylindrical gadget contains seven noise-cancelling microphones (that can be muted) and it plays host to Alexa, Amazon's answer to Apple's Siri, Google Assistant and Microsoft's Cortana. Alexa is a human-friendly intelligent interface that dwells in the Amazon cloud, converting your spoken instructions into actions. It claims to constantly learn and update itself using an array of services to fine-tune its voice recognition capabilities, and the clarity of its 360° omnidirectional loudspeaker system has won many plaudits.

There are numerous ways in which Echo will help users to get more from their home network. Obvious ones include directly interfacing to Amazon's Music or Audible books services, allowing hands-free listening and control of a user's online library (remember that every Amazon CD or music track you buy automatically adds an MP3 into your personal library for downloading or playing on a network device). Weather and traffic reports are now just a voice query away, and online shopping also gets the Echo treatment, because items can be added (though not deleted!) to your Amazon shopping cart using voice commands.

Built into Echo is a hands-free timer that will count down in the kitchen or wake you at appointed times, all programmable using voice commands. By adding more so-called 'skills' using the Alexa app (Android, iOS) Echo will handle more UK-centric tasks such as reading newspaper headlines, checking bus timetables or ordering an Uber ride, but currently the skills feature-set seems thin on the ground: querying Network Rail or Jamie Oliver recipes are two examples quoted by Amazon.

Apart from being a chirpy assistant, Echo also handles the setup of compatible smart devices on your home network, including Hive thermostatic controls, Belkin WeMo devices and Philips Hue smart led lighting (see *Net Work*, May 2014). As you would expect, Echo can act as a Bluetooth loudspeaker as well. Echo is mains-powered and consumes just 500mW in standby. Costing £149.99, the Echo smart speaker is available in a black or white finish, and a smaller sibling, Echo Dot (2nd generation) has a reduced speaker system for bedside or tabletop use, and costs £49.99.

Amazon's Echo is their voice-recognition loudspeaker, with many 'smart' capabilities – available in black or white

Early UK adopters have expressed some mixed views about Echo, citing severe problems when connecting via BT's wireless Home Hub, but the general feeling is that Echo's 'skills' will be fine-tuned over time and the best has yet to come. Google is also working secretively on its own counterpart, and we will be hearing more about Google Home in coming months. Don't be surprised if an Apple device for Apple HomeKit arrives unannounced as well. A major battle to wrest control of the networked home is under way, especially if Amazon Echo steals traffic away from Google and all the advertising revenue that it brings the eponymous search engine.

Echo Dot is a smaller, cheaper device for bedside or tabletop use

Dashed to pieces

Last year, I highlighted Amazon Dash Buttons, the proprietary system that allows US Amazon customers to add regular consumables and groceries to a shopping cart, with the touch of a button. Stick a dedicated Wi-Fi Dash Button by the washing machine, for example, to re-order a box of Tide washing powder or use different Buttons to re-order other products. Dash Buttons have been likened cruelly to a Skinner box, in which lab rats learn to press a lever and receive a reward. In the US, Amazon Dash Buttons cover more than 150 products, everything from nappies (diapers) to Play-Doh. The choice is very restricted though, and prices need close scrutiny. The enjoyable Fastcodedesign blog at **http://tinyurl.com/pfsbed7** gives an insight into a life filled with Dash Buttons. As you would expect, Dash Wi-Fi Buttons have already been hacked and re-coded to re-purpose them for something else (such as calling an Uber taxi or ordering a pizza, see Dash Button Dudes website at: **http://tinyurl.com/hubfwwk**).

Britain is heading in the same direction, as Amazon UK has now launched Dash, a Wi-Fi barcode-scanning wand, for some London-based AmazonFresh customers that makes re-ordering seamless. Amazon has also been given the green light by Britain's Civil Aviation Authority to test-fly their drones, with impressive-looking footage appearing on TV of a drone landing on someone's lawn. It may be pie-in-the-sky, but they aim to deliver within 30 minutes of ordering.

That's all for this month's Net Work. You can contact the author at **alan@epemag.net** or send comments for possible inclusion in Readout to **editorial@wimborne.co.uk**

CIRCUIT SURGERY

REGULAR CLINIC

BY IAN BELL

Op amp instability – Part 2

LAST MONTH, in response to an *EPE Chat Zone* post from user ***lost***, we looked at some of the fundamentals of op amp amplifier circuits, examining feedback in the context of amplifier stability and defining some relevant terms and concepts. After reading the article, ***lost*** commented about finding the idea of breaking the loop to define the loop gain confusing, so we will look at that in more depth. We will then look at the effect on the stability of the circuit of adding capacitance to the loop. At the op amp input part of the loop this is most likely to be parasitic capacitance (eg, circuit board tracks). Parasitic capacitance can occur at the output too, but problems here are often related to deliberately trying to drive capacitive loads. Since we have looked at problems with capacitive loads before, this month we will mainly focus on capacitance at the input.

Erratum

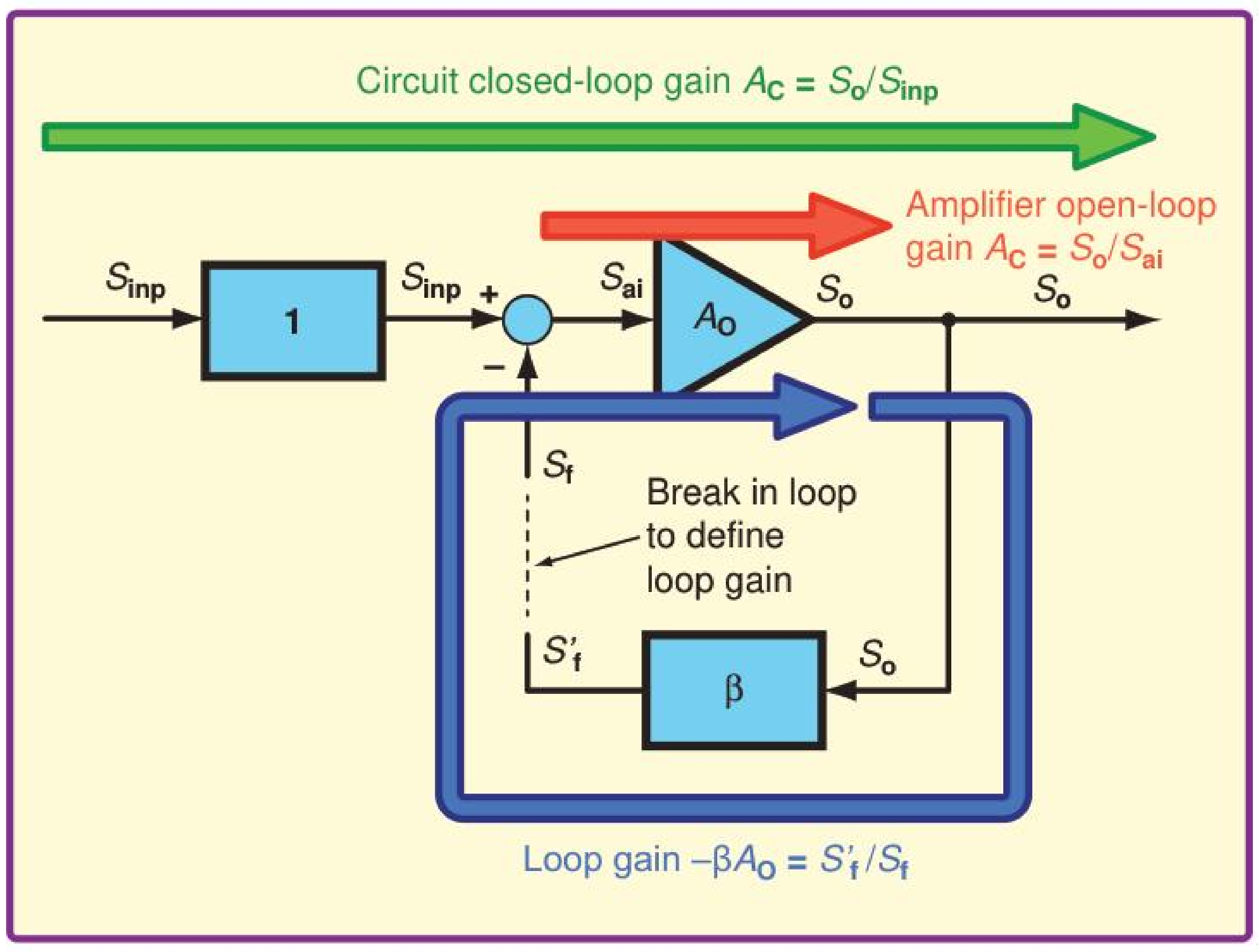
Fig.1 is a copy of Fig.4 from last month. Before discussing the issues with 'breaking the loop' we would like to point out that there was a typographic error in last month's Fig.4. The text 'Break in loop to define *open* loop gain' should have read 'Break in loop to define loop gain'. This is corrected in this month's Fig.1.

Breaking the loop

lost summarised his confusion about breaking the loop: 'With the loop broken there is no S_f, hence infinite loop gain'. If the circuit was built with an ideal op amp (with infinite open-loop gain, A_O), and we actually disconnected the feedback, the circuit gain, S_o/S_{inp} in Fig.1, would be infinite, unlike the value of S_o/S_{inp} with the feedback in place (the closed-loop gain). However, the gain along the loop path, $-\beta A_O$, is infinite (if A_O is infinite) whether or not the loop is broken. The presence of feedback allows us to form a finite closed-loop gain amplifier from an infinite open-loop gain ideal op amp, but the gain of the op amp itself does not change when the feedback is applied.

Lost's confusion possibly results from a misunderstanding of our purpose in breaking the loop in last month's discussion. This was to develop the definition of loop gain from the system diagram (Fig.1), not to operate the circuit with the feedback removed.

We can define the 'gain' between any two points in a circuit where there is a path of influence from one point to another. Let's call them 'start' and 'finish' as they do not have to be the normal input and output. The gain is then defined as: V_{finish}/V_{start}. This approach is used in noise analysis where, for example, finding the noise at the output requires us to know the noise generated by each component and the gain from that point to the output.



Circuit closed-loop gain $A_C = S_o/S_{inp}$
Amplifier open-loop gain $A_C = S_o/S_{ai}$
S_{inp}
1
S_{inp}
+
−
S_{ai}
A_O
S_o
S_o
S_f
Break in loop to define loop gain
S'_f
β
S_o
Loop gain $-\beta A_O = S'_f/S_f$

Fig.1. Structure of an amplifier with negative feedback showing open-loop, closed-loop and loop-gain relationships. (Fig.4 from Circuit Surgery *November 2016 with correction to Fig.text – see article for details.)*

Loop gain

In the context of the loop gain for the system diagram in Fig.1 we need to find the gain around the closed loop of the feedback path. By definition the start and the end of a loop are the same point, so if we write the gain as defined in the previous paragraph we end up with say, V_{start}/V_{start}, which is 1. This does not achieve what we want.

In Fig.1 we could define loop gain as S_f/S_{ai}, which at first might look OK; however, this does not include everything in the loop – it misses the part which subtracts the feedback from the input and consequently gives the loop gain as βA_O rather than $-\beta A_O$. It could be said that it is easy to just add a minus sign if we want to take account of this, but we should feel uncomfortable that we did not include the entire loop – if we try a similar thing in a different situation we might encounter more difficult issues.

The approach of breaking the loop, described last month and shown in Fig.1, allows us to define two different signals S_f and S'_f which are really at the same point in the loop. This allows us to define a gain for the complete loop path that does not cancel to 1. We trace the entire path of the loop in the system diagram from, and back to, the break, so it does not matter where the break is – we get the same expression for loop gain.

Using a broken loop

We broke the feedback loop simply for the purposes of defining loop gain with a gain expression similar to the ones used for open-loop and closed-loop gain. It is also possible to break the loop of a feedback circuit for the purposes of more detailed analysis, simulation or even measurement. The aim of doing this is to obtain information about the loop characteristics, which for more detailed circuit models than Fig.1 may be difficult to do with the feedback in place. The process must be done with care however – the output driving the break may have to be loaded with the same impedance it sees in the normal circuit, and the DC conditions need careful attention so that the bias levels in the 'broken' circuit match the ones in normal operation.

For example, in simulation the correct DC levels can be achieved by breaking the loop by inserting an extremely high-valued inductor instead of a pure open circuit. The inductor can have a totally unrealistic value – for example gigahenries (the simulator does not know about the limits of components we can actually obtain). This effectively keeps the loop closed for DC (for which the inductor is a short circuit), preventing any small DC levels being open-loop amplified to cause the amplifier output to saturate at the supply levels.

For AC signals, this super-sized inductor has an extremely high impedance and effectively breaks the loop, allowing the simulation, in which a test signal is injected at the 'input' side of the loop-break, to show the AC characteristics of the loop (ie, the frequency response of the loop gain). Often, the loop will be broken at the input to the feedback network and the response measured at the amplifier output.

In our path tracing through the system diagram to obtain the loop-gain expression we implicitly did *not* worry about the circuit input (S_{inp}) as that was not on our path of interest. However, in (for example) a detailed 'broken loop' simulation it will influence the circuit. Typically in such cases the input is explicitly set to zero signal. To put it crudely, this keeps it quiet so what we see at the output is just the characteristics of the loop. More formally we assume the system is linear for small signal variations around a fixed operating point, and therefore the total output signal is the sum of the contributions of all input signals. If we set all input signals apart from one to zero then we see the characteristics with respect to the active input at the point (output) being observed.

Input capacitance

The circuit in Fig.2 is a standard non-inverting op amp amplifier. When we build this circuit there will inevitably be some capacitance C_P, present on the inverting input of the op amp, as shown in Fig.3. This capacitance is a combination of the op amp input capacitance, the capacitance of the physical grounded resistor R_G, and the capacitance of the circuit board tracks connecting the resistors to the op amp's input. The capacitance is in the feedback loop and will therefore affect the loop gain and potentially the stability of the circuit.

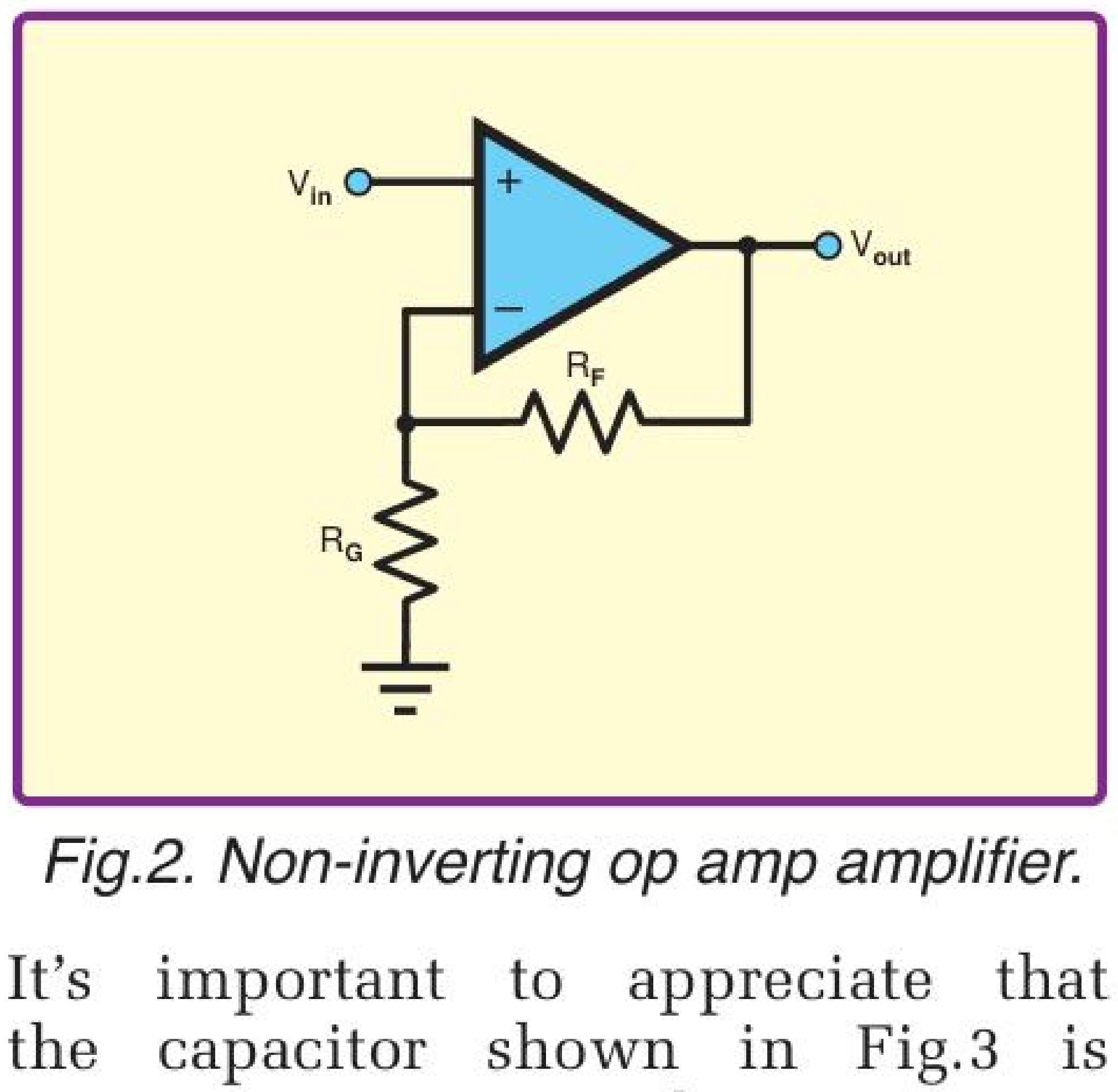


Fig.2. Non-inverting op amp amplifier.

It's important to appreciate that the capacitor shown in Fig.3 is not a component in the circuit – it represents the capacitance inherent in the components and wiring and is referred to as a 'parasitic capacitance'. We include it in the schematic not as an instruction for construction, as would be the case in a project schematic, but to help us understand the undesirable effects it might have and as the starting point for circuit analysis that will help gain insights into these effects.

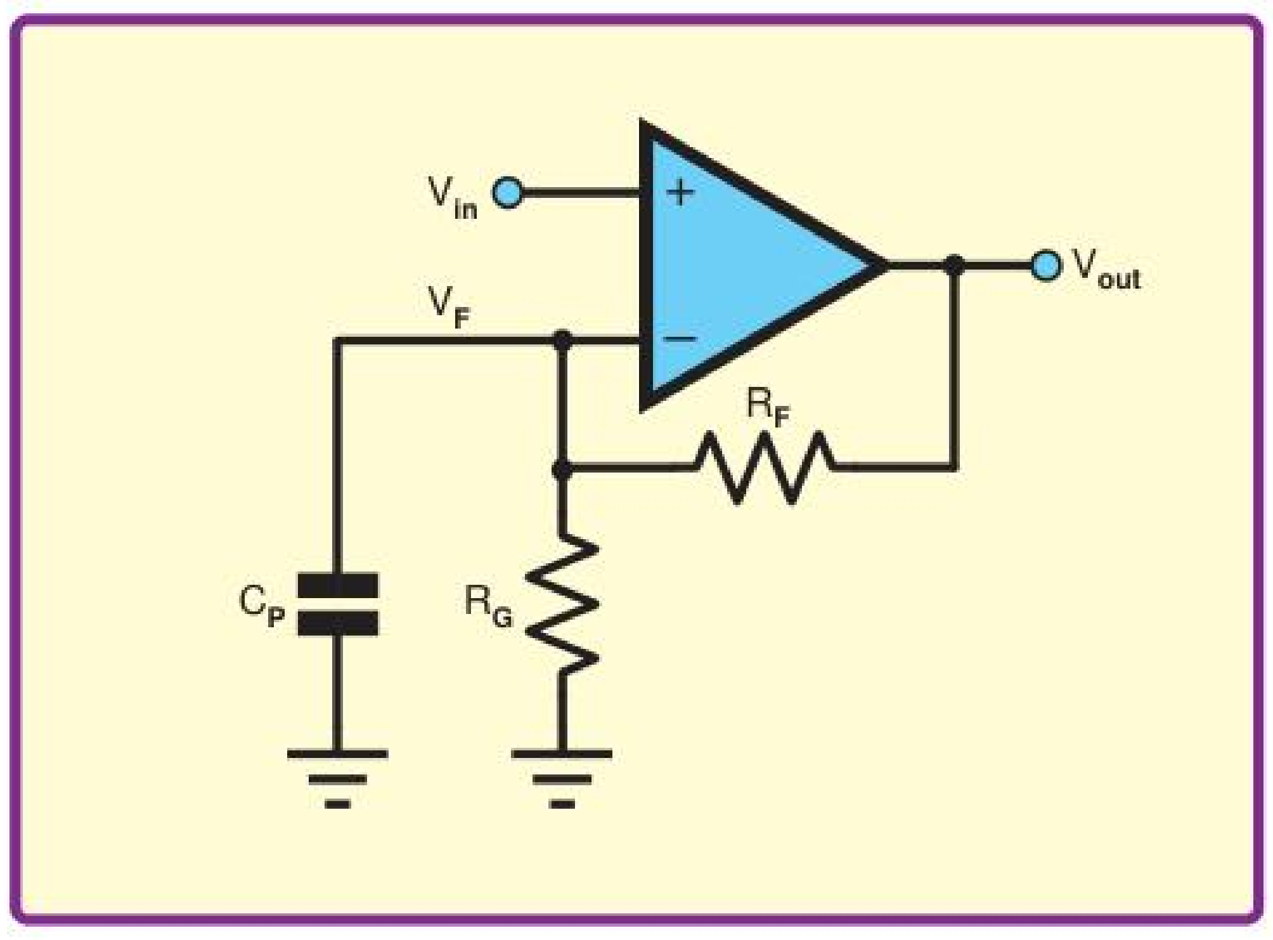


Fig.3. Non-inverting op amp amplifier with parasitic capacitance at the input shown

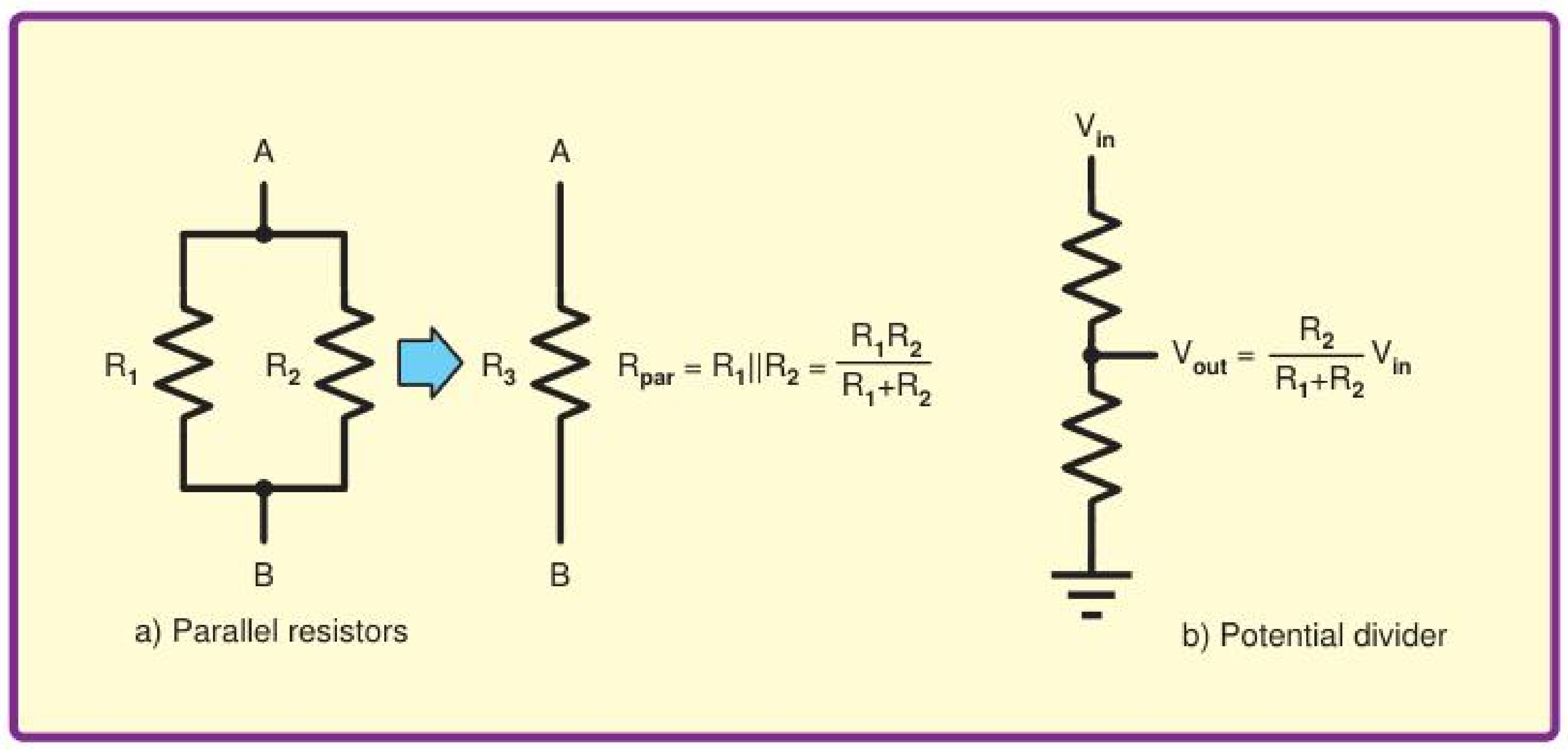


Fig.4. Useful formulae

Analysis preliminaries

An analysis of the circuit is exactly what we are going to do, but before starting it is useful to note a couple of common formulae that will help us. First, if we have two resistors, R_1 and R_2 connected in parallel, as shown in Fig.4a, then their combined resistance is given by:.

$$R_{par} = R_1 \| R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

Here, $R_1 | | R_2$ is used to mean the parallel value of R_1 and R_2. Second, for a potential divider, as shown in Fig.4b, the relationship between the input and output voltages is given by:

$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$

Finally, for a capacitor C, we can denote its reactance as X_C – this is the 'resistance' of the capacitor, which depends on frequency and which will determine both the frequency-dependent amplitude and frequency-dependent phase shift in circuits built from combinations of resistors and capacitors. Circuits build entirely from (ideal) resistors do not cause changes in amplitude to vary with frequency and do not introduce any phase shift.

Feedback Structure

Last month, we discussed the non-inverting op amp amplifier circuit (Fig.2) which has a feedback structure that is represented by the system diagram in Fig.1. The feedback βA_O is obtained from the potential divider formed by R_F and R_G and so loop gain is given by:

$$-\beta A_O = -\left(\frac{R_G}{R_G + R_F}\right) A_O$$

Here, we must remember that the amplitude and phase shift of A_O varies with frequency.

Thus, the general shape of the loop-gain frequency response for the circuit in Fig.2 will be set by the frequency response of the op amp and will look something like that shown in Fig.5. Typically, an op amp will have a low-frequency pole (eg, 10s of Hz) which will result in the gain starting to fall above this frequency (poles were discussed last month). The op amp's next pole is at a much higher frequency and adds another 90° of phase shift, potentially producing instability if the gain has not dropped sufficiently. Again, as discussed last month, we can measure the stability of the circuit using the gain and phase margins, as shown on Fig.5.

The effect of the resistor-based feedback network (Fig.2) on the graph in Fig.5 is simply to shift the whole amplitude response curve up or down, while not affecting the phase shift. The simple shift of the gain curve with β occurs because we are using a log scale in decibels (dB), so a change in constant multiplication factor results in constant addition or subtraction to the dB gain value. Decreasing the closed-loop gain by increasing β shifts the whole amplitude curve up, which, as can be seen in Fig.5, reduces the gain margin (remember the phase curve is not changed by the resistor network). This illustrates the point made at the end of last month's article that circuits with low closed-loop gain are more likely to be unstable.

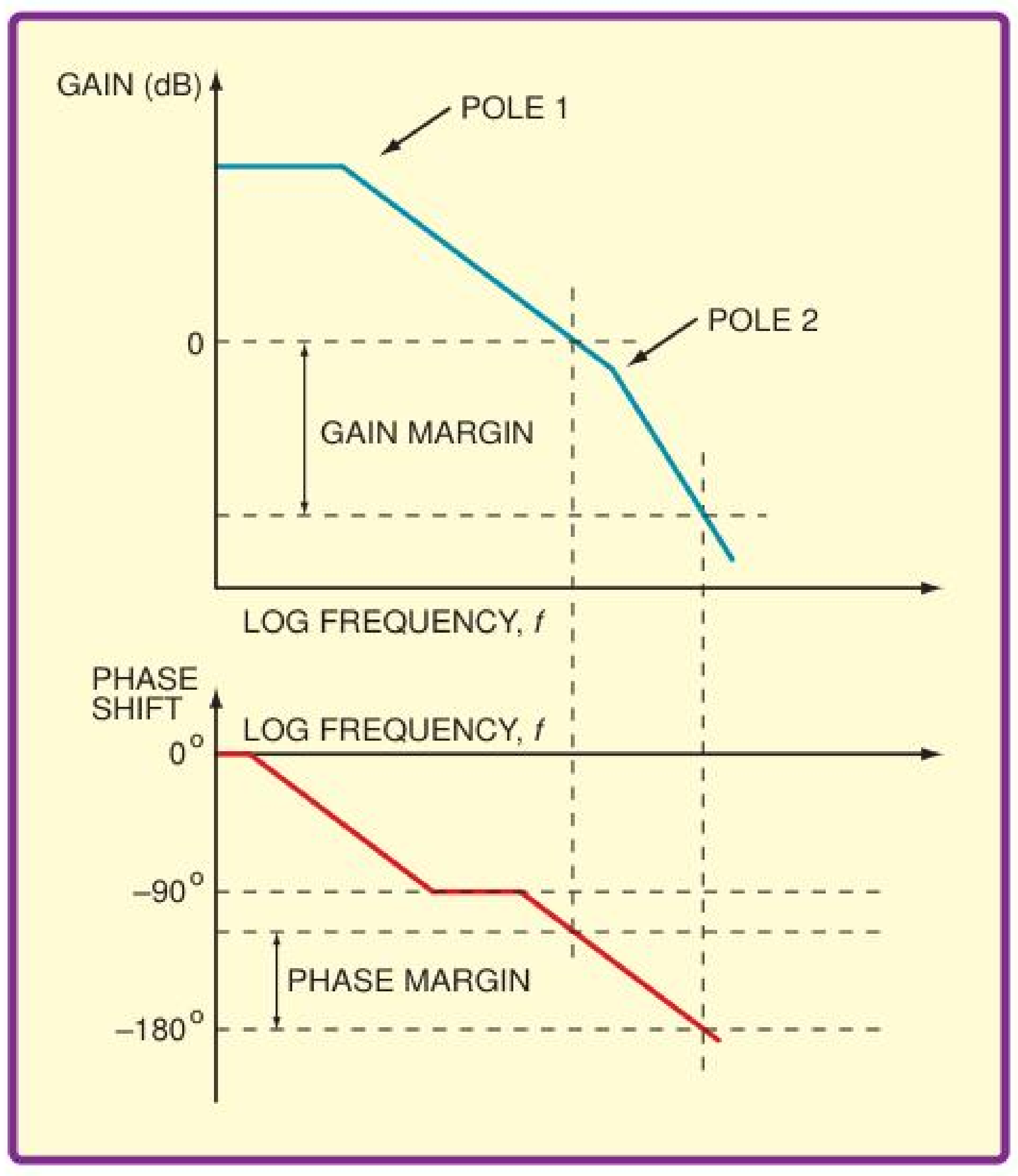


Fig.5. Variation of gain and phase shift around a feedback loop (loop gain) with signal frequency, illustrating gain margin and phase margin.

Parasitic capacitor analysis

Looking at the circuit in Fig.3, we need to find an expression for β so we can obtain the loop-gain equation. If we assume an ideal op amp with infinite input impedance then this is a matter of finding the value of V_f/V_{out} in terms of the two resistors and capacitor. This is the same situation as finding β for Fig.2, except we have an additional component to contend with.

We note that the parasitic capacitor and R_G are in parallel, so their combined impedance can be obtained from the parallel-resistors formula (using R_G and X_{CP}). The parallel resistor and capacitor combination form a potential divider with R_F so we can use the potential divider formula from above with $R_1 = R_F$ and $R_2 = R_G \,|\,|\, X_{CP}$. This gives a formula for β as follows:

$$\beta = \frac{V_f}{V_{out}} = \frac{\left(\dfrac{R_G X_{CP}}{R_G + X_{CP}}\right)}{R_F + \left(\dfrac{R_G X_{CP}}{R_G + X_{CP}}\right)}$$

This is bit cumbersome, but we can tidy it up by multiplying both the numerator and denominator by $R_G + X_{CP}$, giving:

$$\beta = \frac{R_G X_{CP}}{R_F R_G + R_F X_{CP} + R_G X_{CP}}$$

Thus for the circuit in Fig.3 the loop gain is:

$$-\beta A_O = -\left(\frac{R_G X_{CP}}{R_F R_G + R_F X_{CP} + R_G X_{CP}}\right) A_O$$

We can see that there is additional frequency-dependence (not just A_O), but this equation does not provide a very clear insight into what is happening. However by doing some further algebra we can get the loop-gain equation into a more useful form.

Equation bashing

Taking the expression for β and dividing both the numerator and denominator by X_{CP}, gives:

$$\beta = \frac{R_G}{\dfrac{R_F R_G}{X_{CP}} + \left(R_F + R_G\right)}$$

Next we divide both the numerator and denominator by $(R_F + R_G)$, giving:

$$\beta = \frac{\dfrac{R_G}{\left(R_F + R_G\right)}}{\dfrac{R_F R_G}{\left(R_F + R_G\right)} \dfrac{1}{X_{CP}} + \dfrac{\left(R_F + R_G\right)}{\left(R_F + R_G\right)}}$$

This looks a bit messy, but the numerator (part of the equation above the line) is equal to the β of the circuit without the parasitic capacitor, which is useful to have there. Looking at the denominator we see that the second term cancels to 1 and the first term contains the expression for the parallel value of R_F an R_G, so we can write:

$$\beta = \left(\frac{R_G}{R_F + R_G}\right)\left(\frac{1}{\left(R_F \| R_G\right)/X_{CP} + 1}\right)$$

With parasitic input capacitor present the loop gain of the circuit in Fig.3 is:

$$-\beta A_O = \left(\frac{R_G}{R_F + R_G}\right)\left(\frac{1}{\left(R_F \| R_G\right)/X_{CP} + 1}\right) A_O$$

Comparing this with the loop gain without the parasitic capacitor:

$$-\beta A_O = -\left(\frac{R_G}{R_G + R_F}\right) A_O$$

We see that adding the capacitor has multiplied the original loop gain by a term that depends on the parasitic capacitance and the parallel combination of the feedback resistors.

Getting complex

One of the difficulties of discussing topics like amplifier stability is that a proper analysis requires use of 'complex numbers', but readers may not be familiar with their use, unless they studied subjects such as engineering or mathematics to university level. AC signals have both amplitude and phase, so a single 'ordinary' number (eg, for the voltage or the gain) cannot encompass the whole picture. Complex numbers have two parts (called 'real' and 'imaginary') and so are able to represent AC signals and circuit characteristics. In the following discussion we will briefly use a complex number and then convert the result to ordinary numbers.

The impedance of a capacitor C, is given by $X_C = 1/sC$ when working with complex numbers. s is a complex number frequency variable and C is the capacitance of the capacitor. A pole is defined as a point where the complex number frequency response (gain) becomes infinite (hence the name 'pole' as a high point in the response). Note that this infinity occurs in a mathematically transformed representation of the circuit's equations – the magnitude of the gain at the pole in ordinary frequency is not infinite – here the pole manifests as a breakpoint in the curve where the slope changes, as seen in Fig.5 and discussed last month.

Looking at just the additional term in loop gain due to the parasitic capacitance and using complex impedance for C_P we get:

$$\frac{1}{\left(R_F \| R_G\right)/X_{CP} + 1} = \frac{1}{R_{Eq} C_P s + 1}$$

Here, R_{Eq} represents the equivalent parallel resistance of R_G and R_F. We note this term becomes infinite when the numerator is zero and will cause the overall loop gain to become infinite (so we have a pole) by virtue of the fact that it is a multiplied term within the full loop-gain equation. This pole occurs when:

$$R_{Eq} C_P s + 1 = 0$$

(Remember, dividing one by zero gives infinity.) We rearrange this to solve for the value of s, that is the complex frequency of the pole:

$$s = -\frac{1}{R_{Eq} C_P}$$

Moving back to ordinary frequency we get the frequency of the pole due to the parasite capacitance, f_p as:

$$f_p = \frac{1}{2\pi R_{Eq} C_P}$$

The 2π occurs because s uses radian-based measurement of frequency, but we want the value in hertz. The minus sign goes because finding the magnitude of the complex number includes squaring the relevant values. We will refer to this as the 'feedback pole'.

Feedback pole

The feedback pole is additional to the two poles already present in the loop gain due to the op amp (as shown in Fig.5). Its effect on stability depends on its frequency relative to the op amp poles, specifically to the higher frequency pole (pole 2 in Fig.5). If f_p is much higher than op amp pole 2 then the circuit is likely to be stable because, assuming the circuit is stable without the capacitance, the loop gain has already decreased below one before the feedback pole has any effect.

If the feedback pole is close to, or below, the op amp pole 2 frequency, then there is a possibility of instability because the feedback pole will add some phase shift while the loop gain is still large. The actual feedback-pole frequency depends on the resistor values and the amount of parasitic capacitance. Typical values for C_p are in the range 2pF to 10pF, but could be higher if board layout is poor. With at least one resistor in the relatively low kΩ range, and good board layout, the feedback pole is likely to be in the order of tens of MHz and will probably be OK. If both resistors are large, for example hundreds of kΩs or more, and the board layout is not so good, then the feedback pole may be in the order of low hundreds of kHz and is likely to cause instability. Large resistor values are sometimes used with CMOS op amps to keep power consumption very low and such circuits may be susceptible to this problem.

Op amp amplifier stability can be improved by adding a capacitor, C_F, across the feedback resistor as shown in Fig.6. The value of C_F is usually chosen so that $R_G C_p \le R_F C_F$. If $R_G C_p = R_F C_F$ the feedback pole is exactly cancelled. Larger values of C_F are OK, but will reduce the amplifier's bandwidth and smaller values may be

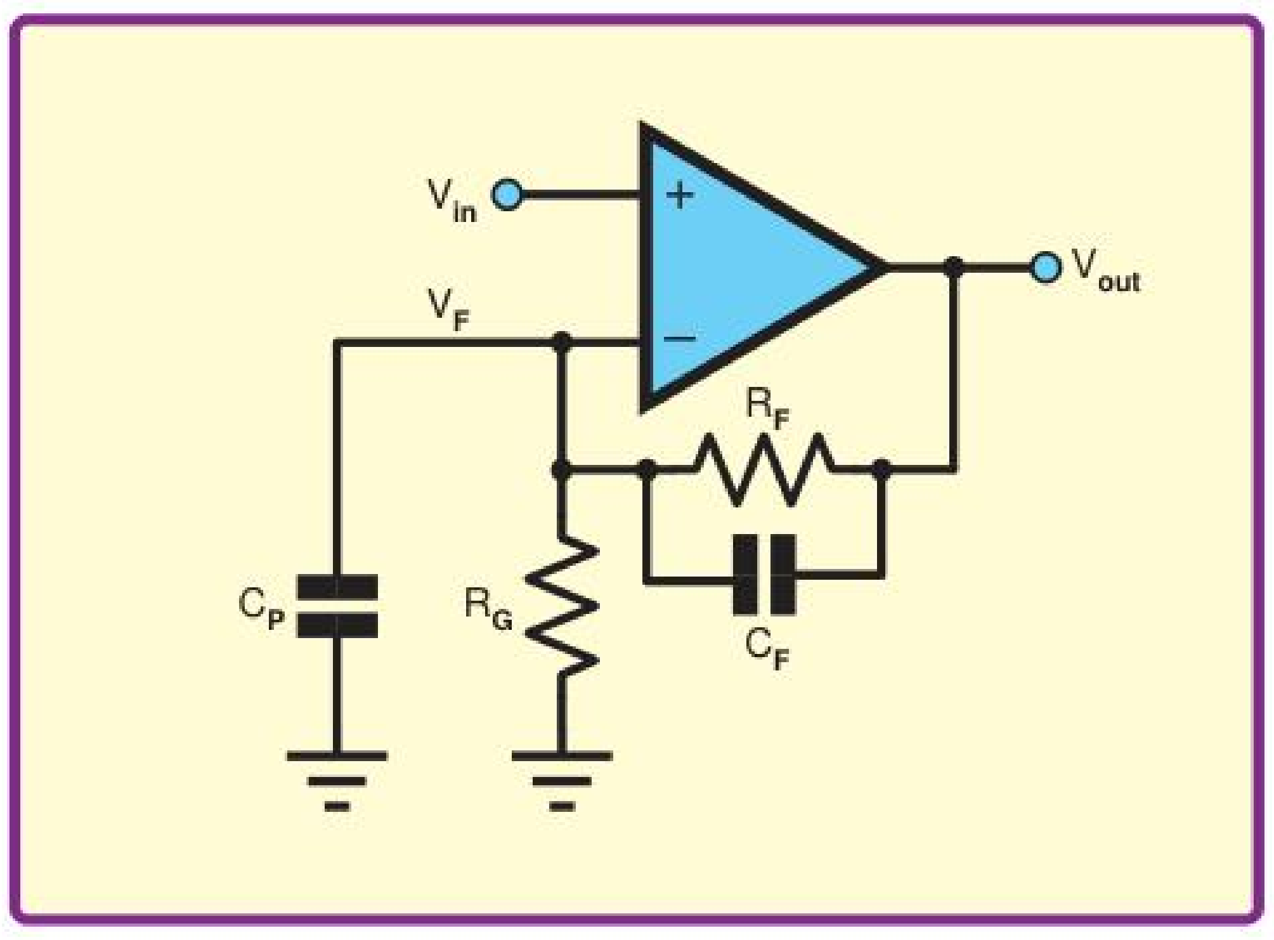


Fig.6. Non-inverting op amp amplifier with parasitic capacitance at the input and feedback capacitor added for stability.

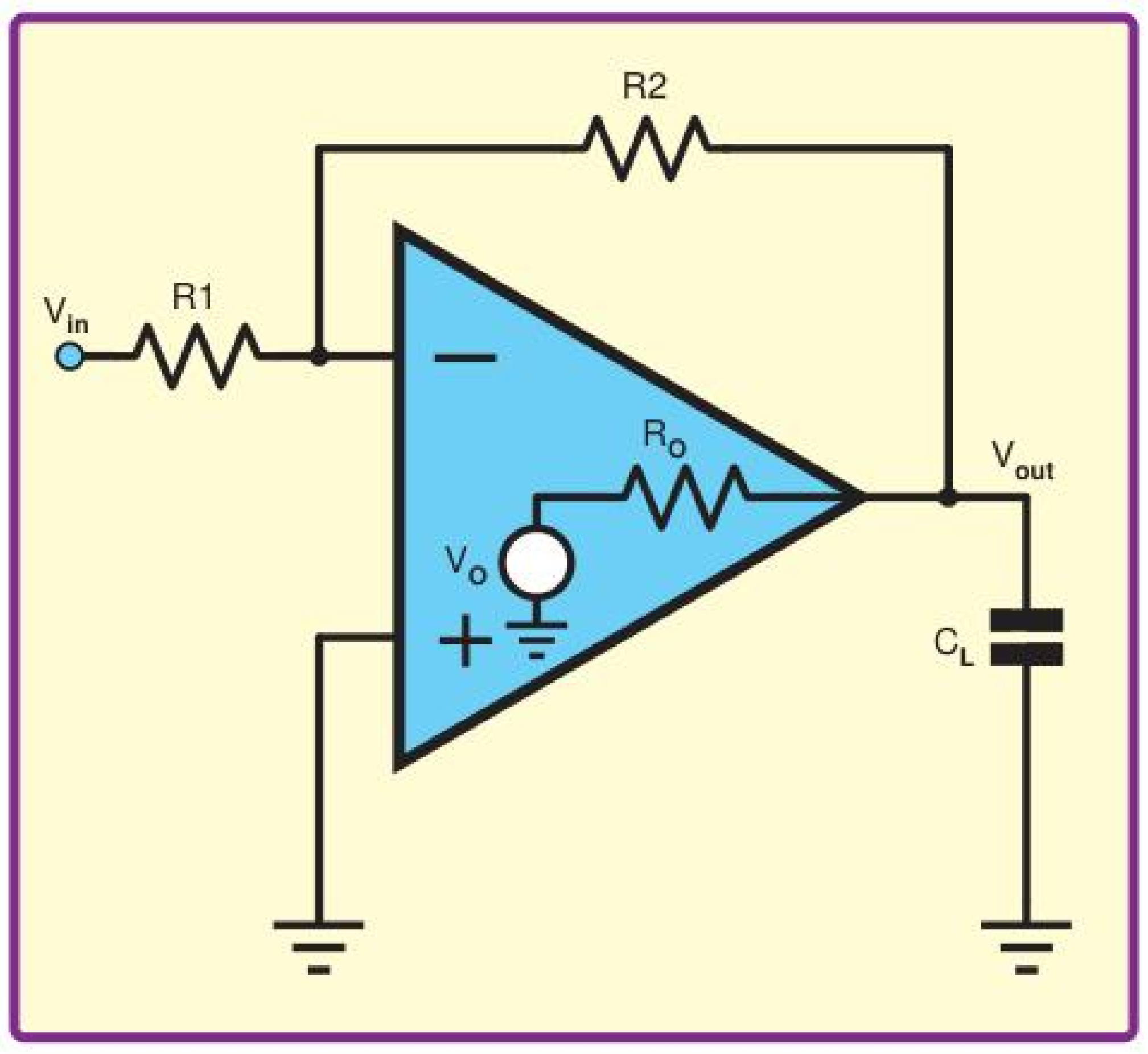


Fig.7. Op amp amplifier with capacitive load showing op amp output resistance

sufficient to prevent instability. In some designs C_F can be obtained by suitable PCB layout without adding a capacitor component; however, small capacitors are often added across feedback resistors for stability. Finding the optimum value may take some experimentation as the exact value of C_p is probably unknown.

Capacitive loads

To finish we will look briefly at the effect of capacitance on op amp output. This was previously covered in more detail in the February 2015 issue of *EPE*. When we add a capacitive load to an op amp amplifier, as shown in Fig.7, we form an RC low-pass filter with the op amp's output resistance, which adds a pole to the circuit's frequency response, and which, like the feedback pole, may cause instability.

The effective output resistance of an op amp is reduced by feedback. However, as frequency increases the gain of the op amp decreases and therefore so does the amount of feedback, increasing the effective output impedance. Increasing impedance with increasing frequency is like the behaviour of an inductor, so R_O looks like it has an inductance in parallel with it. This inductance forms a resonant circuit with the load capacitance, which may result in ringing or oscillation.

There are a number of ways to improve the stability of a circuit in which an op amp drives a capacitive load. The simplest is to add a resistor between the op amp's output and the capacitor, as shown in Fig.8. This isolates the capacitor from the op amp's feedback circuit and modifies the frequency response to a more stable situation. We can also think of it as damping the resonant circuit just discussed.

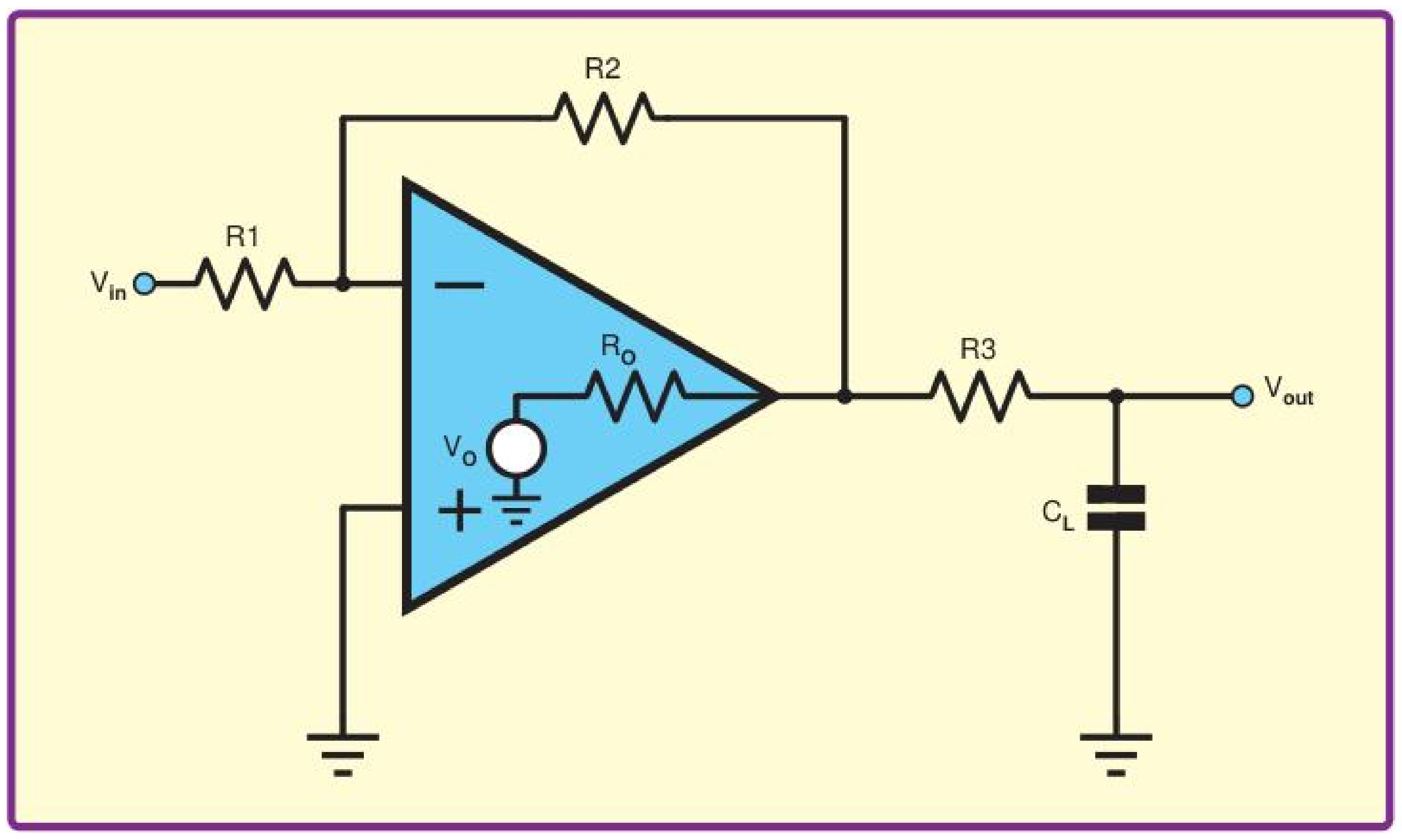


Fig.8. Op amp amplifier with resistor added to prevent instability due to capacitive load

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PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

PICs and the PICkit 3: A beginner's guide – Part 7

WE'RE coming towards the end of an interesting year in the PIC world, especially with Microchip's acquisition of Atmel and the release of their cloud-based development platform. I hope to have a closer look at Microchip's Xpress Board and their IDE in the new year (now that they're more readily available) and I look forward to seeing what exciting technologies 2017 brings us.

Over the last six months we've covered a lot of ground in our *Beginner's Guide* using the Low Pin Count Demo Board. Last month, we put our knowledge to use by building our first project – a *Traffic Light*. We have another nine Microchip PIC lessons to cover, which will enable us to go over some quite complicated and sophisticated ideas. I will be doing another project once we complete Lesson 10 and then a final project upon completion of Lesson 13. In the next two projects, I want to transition away from the Low Pin Count Demo Board into building our own breadboard design with discrete components. So stick with 'the programme' – it's going to get exciting!

You will gain a greater insight into PICs and what we're trying to achieve if you read the previous articles in this series. You will also need the following software and hardware:

1) Purchase the PICkit 3 Low Pin Count Demo Board (**http://tinyurl.com/h2jj2ek**)
2) Purchase the PICkit 3 Programmer + USB Cable (**http://tinyurl.com/zcpx3le**)
3) Download *PICkit 3 Starter Kit User's Guide* (**http://tinyurl.com/jyqfeuk**)
4) Download MPLAB X IDE (**http://tinyurl.com/hmehqja**)
5) Download XC8 Compiler (**http://tinyurl.com/h5g9k5l**)

This month, we're going to take the next three lessons from the *PICkit 3 Starter Kit User's Guide:* Variable Speed Rotate, Debounce and Reversible Variable Speed Rotate.

Lesson 5 Variable Speed Rotate

In this lesson, we take and expand ideas from two previous lessons: 'Rotate' and 'Analog to Digital Conversion'. Lesson 3 covered a simple rotate between the four LEDs on the Demo Board. Before each change to the next LED, there's a small 500ms delay. Using what we learnt in Lesson 4 on ADCs, we can now capture the input from the Demo Board's potentiometer and replace the 500ms delay value in the rotate example and adjust it. The new delay is based on the captured ADC value, to dictate how fast or how slow the LEDs rotate.

Fig.1 shows a flow chart of what's going on in the code. First, the ADC is configured by setting the correct setup bits – selecting the ADC port to be used and setting it as an input. Next, ports are configured as outputs for the LEDs. Then the PIC grabs the ADC value and determines the delay time. Last, the program moves through the LEDs using right shift.

The listing (top of the next column) shows the code. I'm only looking at the main `while` loop here as it is the most important part. First, it calls a new function called `adc()` and stores the output value in a variable called `delay`. Then a short delay of 5ms is added.

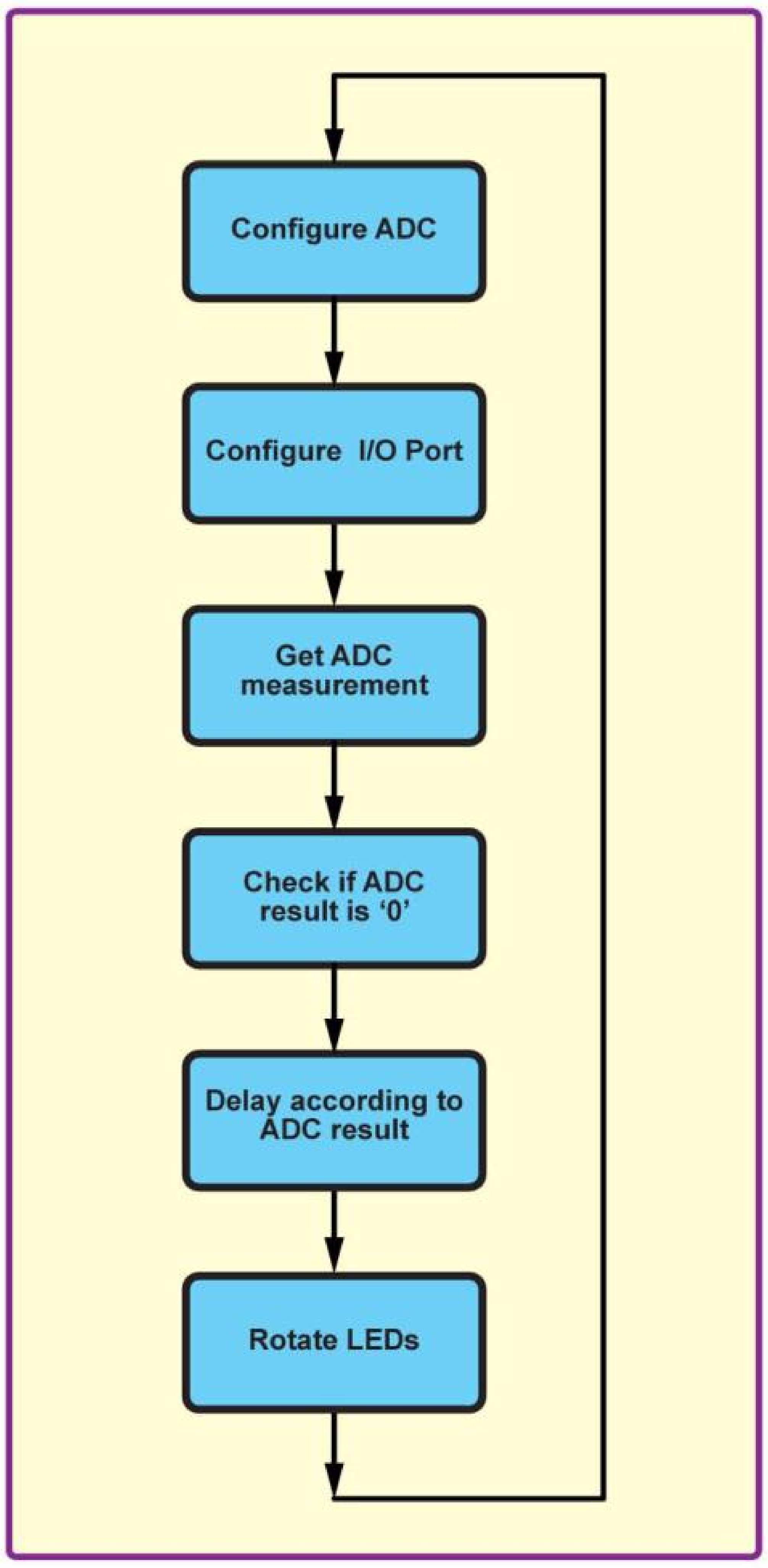

Fig.1. Variable speed rotate flow diagram

```
while (1) {
        delay = adc();
        __delay_ms(5);
        while (delay-- != 0)
                __delay_ms(2);
        LATC >> = 1;
        if(STATUSbits.C)
                LATCbits.LATC3 = 1;
}
```

There's another `while` loop here, that takes the value stored in `delay` and continually decrements it until it becomes 0 (here, decrement means subtract by one). Every time the loop runs, the `delay` variable is decremented and delays the code operation by 2ms, and the larger the `delay` variable, the longer the delay.

Next, there is a right-shift operation in `LATC`, followed by a check to see if the carry bit has been toggled (reset if it has) and then the `while` loop runs again. (We covered the majority of this in previous lessons.)

```
unsigned char adc(void) {
        __delay_us(5);
        GO = 1;
        while (GO) continue;
        return ADRESH;
}
```

Notice the function called `adc()` in the `while` loop. I mentioned last month how you can write functions as very handy 'shorthand' frequently used pieces of code. It's also useful to note that the function is placed outside of the main loop and it must be instantiated before the main loop with the following line: `unsigned char adc(void);`

In our function, the code delays for 5µs, sets the internal `GO` keyword to 1 and waits in the `while` loop until `GO` is set back 0 (which indicates the ADC conversion has completed). To finish the function the code uses a term called `return` followed by the value we want to 'return', which is `ADRESH` (the upper MSB of the captured ADC value). (In any function we can choose to return a value or not to return a value. This is dictated by how we instantiate the function.)

```
unsigned char adc(void);
```

This line means instantiate a function called `adc`, which takes no values (hence the void keyword here) and returns an `unsigned char`, which will be ADRESH.

Lesson 6: Debounce

'Debounce', what an odd word – even my spellchecker doesn't like it! This lesson is really about handling inputs from buttons and switches. 'What's complicated about buttons?' I hear you say. You press them and something changes, right? The simple answer is, they're not *that* complicated, but you do need to know a few tricks to use them properly.

Buttons and switches play a very useful part in human-computer interaction. It may be as simple as a light switch or the button you press on your smartphone to turn it on or off. In the case of a light switch, it physically connects and disconnects the power to lights via brass or copper contacts that move with the switch you press. Have you ever held the switch half way between on and off and watched the lights flicker as the contacts just touch and then separate? I don't recommend doing this too often as you may cause permanent damage to your light or switch. This flickering is similar to a problem we can face with microcontroller designs using *mechanical* switches. The light switch is designed to change its state from disconnected to connected as fast as possible so you don't see flickering in your lights as you throw the switch – but that doesn't mean there isn't any flickering, caused by the moving contacts 'bouncing' as they make or break the circuit – it just happens too quickly for your eyes and brain to register the effect.

However, a PIC microcontroller operates much faster than our eyes. Human eyes capture roughly 60 frames per second, so flickering faster than this is unlikely to be perceived. The PIC's clocks runs at 8MHz and thus can capture much faster transitions. This is not an ideal situation when it comes to monitoring switches. Imagine you want a PIC to count the number of times you press/release a pushbutton. You might think that one press would register as a count of one, but the PIC sees a waveform with multiple transitions and will count those as legitimate switch events – see Fig.2.

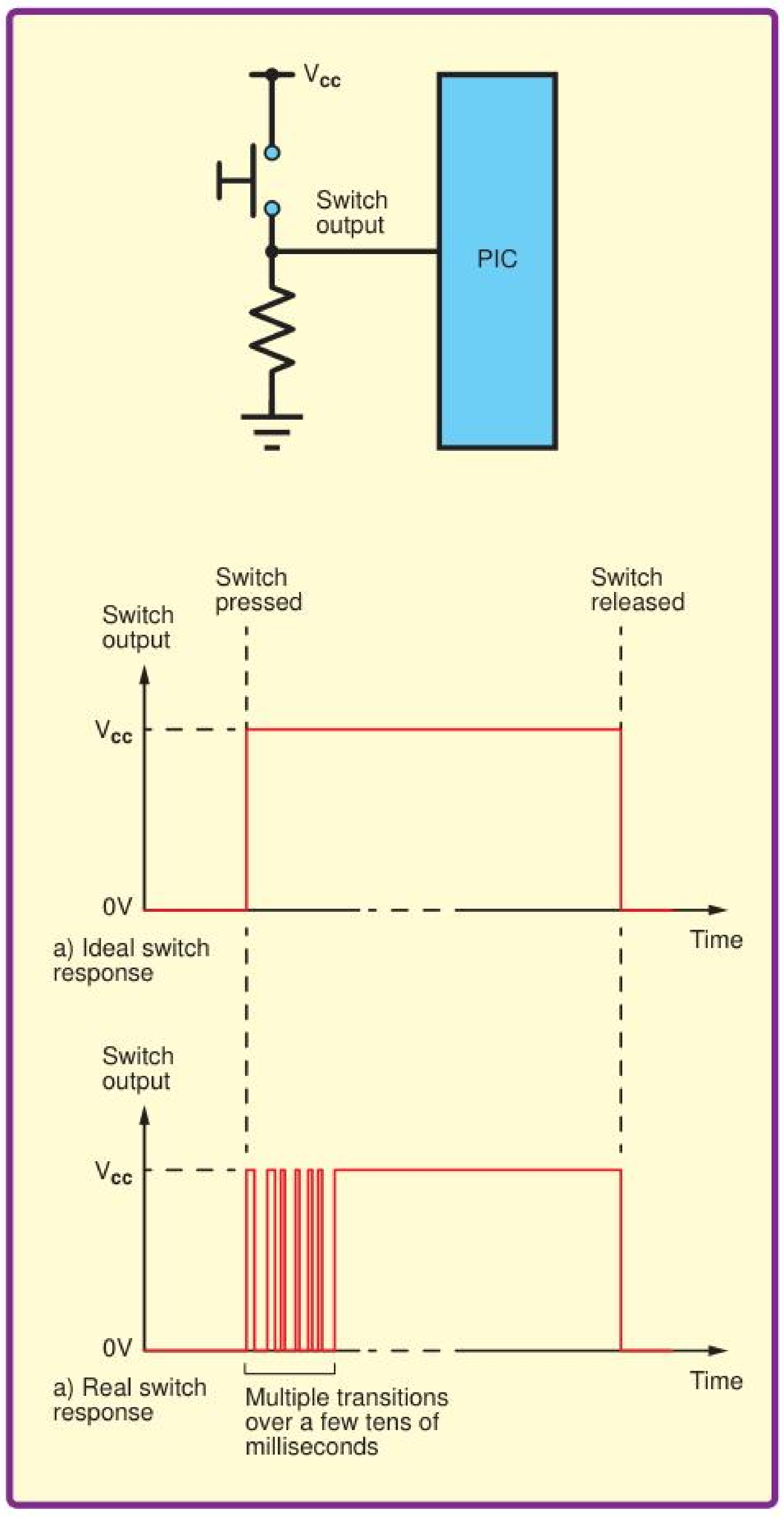

Fig.2. Bouncy switch outputs

What we need is a way of 'debouncing' the switch, or to be precise the output from the switch since there is not much we can actually do about the innards of a component. There are two ways of 'debouncing' an incoming signal – using hardware or software. There are quite a few hardware tricks to debouncing. Using an SR flip-flop is popular, or we can simply add a series resistor to V_{CC} and a capacitor in series – see Fig.3 for our implementation. Consider the resistor-capacitor approach. When the switch or button is not open, the input to the PIC will rise to V_{CC} (5V in our case) and charge the 100nF capacitor. When the switch or button is closed, we will remove the charge from the capacitor at a slow rate. This causes the input to our PIC to see a slowly-falling-to-zero value. We have effectively filtered out the bounce – the downside of this approach is that capturing a change on the input is slowed down. Now let's examine a software approach.

```
while (1) {
        if (SWITCH == DOWN) {
                __delay_ms(10);
                if (SWITCH == DOWN) {
                        LED = 1;
                }
        } else
                LED = 0;
}
```

For the software implementation, we almost do the exact same thing. Examine the `while` loop above. SWITCH is the input from switch SW1 on the Demo Board. We check to see if this is low, if it is, we wait 10ms, then check to see if it is still low, then light the LED. This ensures that the LED, isn't constantly turning on and off. This is a great demonstration of how to make it work, but I think it's more valuable to see the problem we're trying to solve.

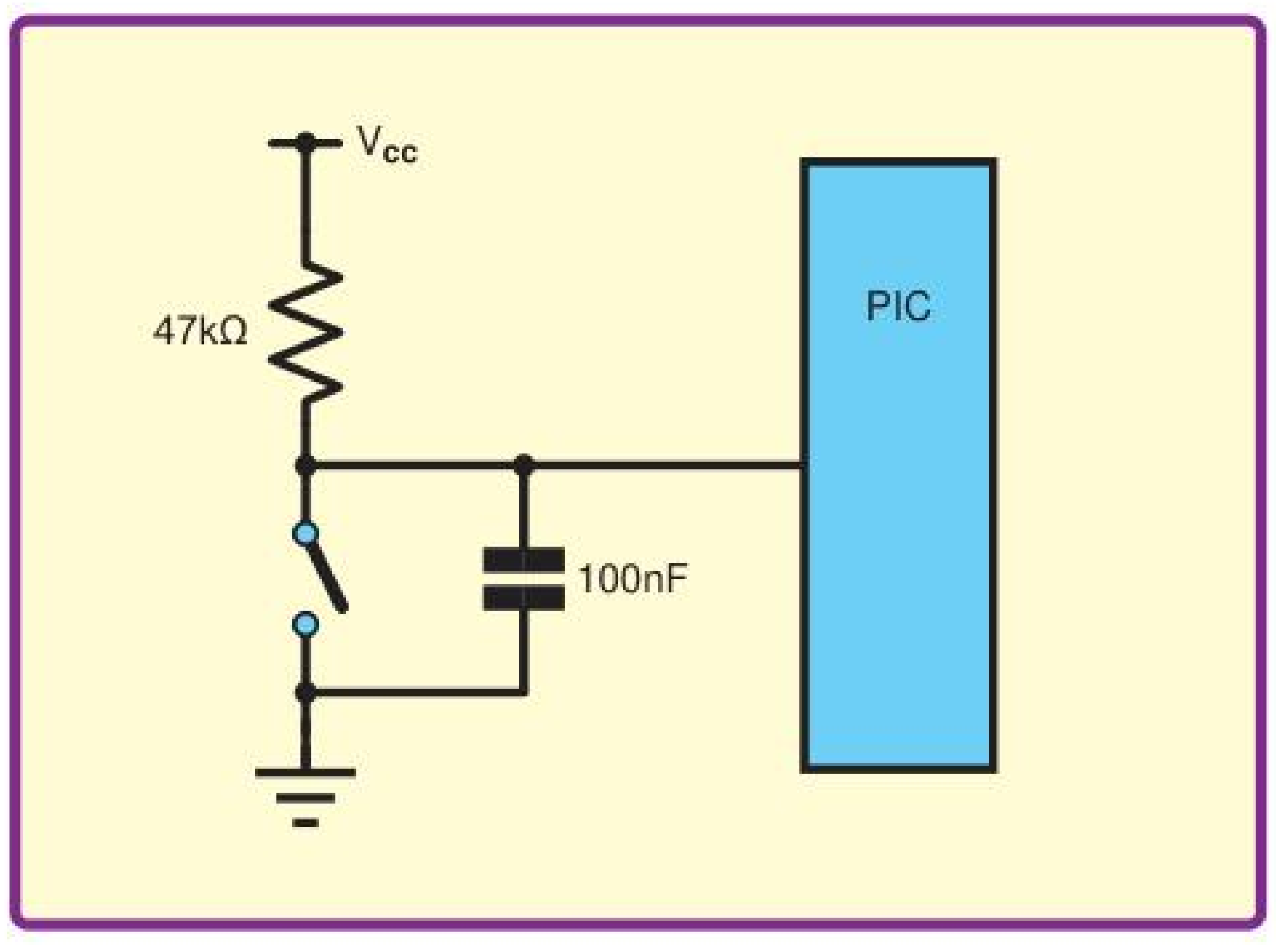

Fig.3. Switch-debounce circuit

```
while (1) {
        if (SWITCH == DOWN) {
                //__delay_ms(10);
                if (SWITCH == DOWN) {
                        LED ^= 1;
                }
        }
}
```

Try the above piece of code. I've removed the else statement to turn the LED off, I've swapped the LED to a toggle (using ^= operator) and I've commented out the 10ms delay. From the code, we should expect that every time we press the button, the LED toggles. However, what we see is a little different. You should notice that every time you press the button, it might toggle and it might not. Hold down the button and you'll see it dim. It is actually toggling, but much faster than our eyes can see. Put the 10ms delay back in and it will toggle as we would expect. This is our debounce fix.

Incidentally, the *Starter Kit User Guide* talks about the same problem, I recommend having a quick read of it.

Lesson 7: Reversible Variable Speed Rotate

This lesson combines everything we've learned in the previous lessons, but here we use the demo board's button to reverse the direction of rotation of the LEDs, it also uses the ADC to adjust the speed of rotation.

The code is quite long, so I'd recommend downloading and having a look at it: **http://tinyurl.com/z2dm5k3**

In the code, we have a function for switch debounce called `check_switch(void)`. This will toggle a global variable called SWITCH_UP. I've touched on local and global variables before. Local variables can only be used in the function where they are instantiated and global variables can be used anywhere.

```
if (check_switch())
      direction ^= 1;
if (direction == LED_RIGHT) {
      LATC >> = 1;
      if(STATUSbits.C)
            LATCbits.LATC3 = 1;
} else{
      LATC << = 1;
      if (LATCbits.LATC4 == 1)
            LATCbits.LATC0 = 1;
}
```

While the rest of the code in this lesson is covered in previous lessons, the above piece is slightly new. The first `if` statement checks the status of the switch. Based on this, it toggles the direction in which the LEDs will rotate. The second `if` statement then looks at the direction and either right shifts or left shifts the LATC bits. (We covered left shifting last month in the *Traffic Light* project.)

There's really nothing else to say about this lesson. It takes everything from previous lessons and puts them together nicely.

Next month

I hope everyone is enjoying the guide so far and that you get a chance to play around with the lessons yourself. We've covered a lot of the basics over the last few months and we'll be moving into more difficult concepts and ideas next month when we look at PWM and timers. These are both very powerful ideas. PWM is used in everything from dimming lights to motor control.

Not all of Mike's technology tinkering and discussion makes it to print.

You can follow the rest of it on Twitter at @*MikePOKeeffe*, up on *EPE Chat Zone* as *mikepokeeffe* and from his blog at *mikepokeeffe.blogspot.com*

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AUDIO OUT

By Jake Rothman

Totally derailed: powering amplifiers – Part 1

This month, I am starting a short series on powering audio amplifiers; a fascinating subject blending aspects of both design and construction techniques.

You would think connecting an amplifier to a power supply would be simple, but it's not. An amplifier can be thought of as a modulated power supply, thus *its* power supply, earthing and wiring arrangements are crucial. When things go wrong, the power supply can end up modulating the amplifier, causing high distortion and noise. Remember, 5mV of a harmonically rich hum waveform is audible from a speaker with the ear right up against it. A tough test, but this is what my customers do.

Regulated or unregulated?

Surprisingly, most power amplifiers use unregulated supplies with just a transformer, rectifier and smoothing capacitor. This is in contrast to most electronic systems, which normally use stabilised power supplies. The reason for this is because it is cheaper and more effective to design the amplifier to have a very high power supply rejection ratio (PSRR). This can be defined as the ratio of change in output voltage to a change in power rail voltage multiplied by the closed-loop gain expressed in dB, but there is no official standard. For a typical power amplifier this is in the order of 60dB with standard 100Hz sawtooth ripple on the power rail – almost as good as a regulated power supply. Using constant-current sources and filtering the input and driver stages helps achieve high PSRR values. The power fed to the output stage normally remains unregulated. 100% negative feedback in unity-gain output stages, a filtered driver stage supply and global negative feedback prevents hum entering the speaker.

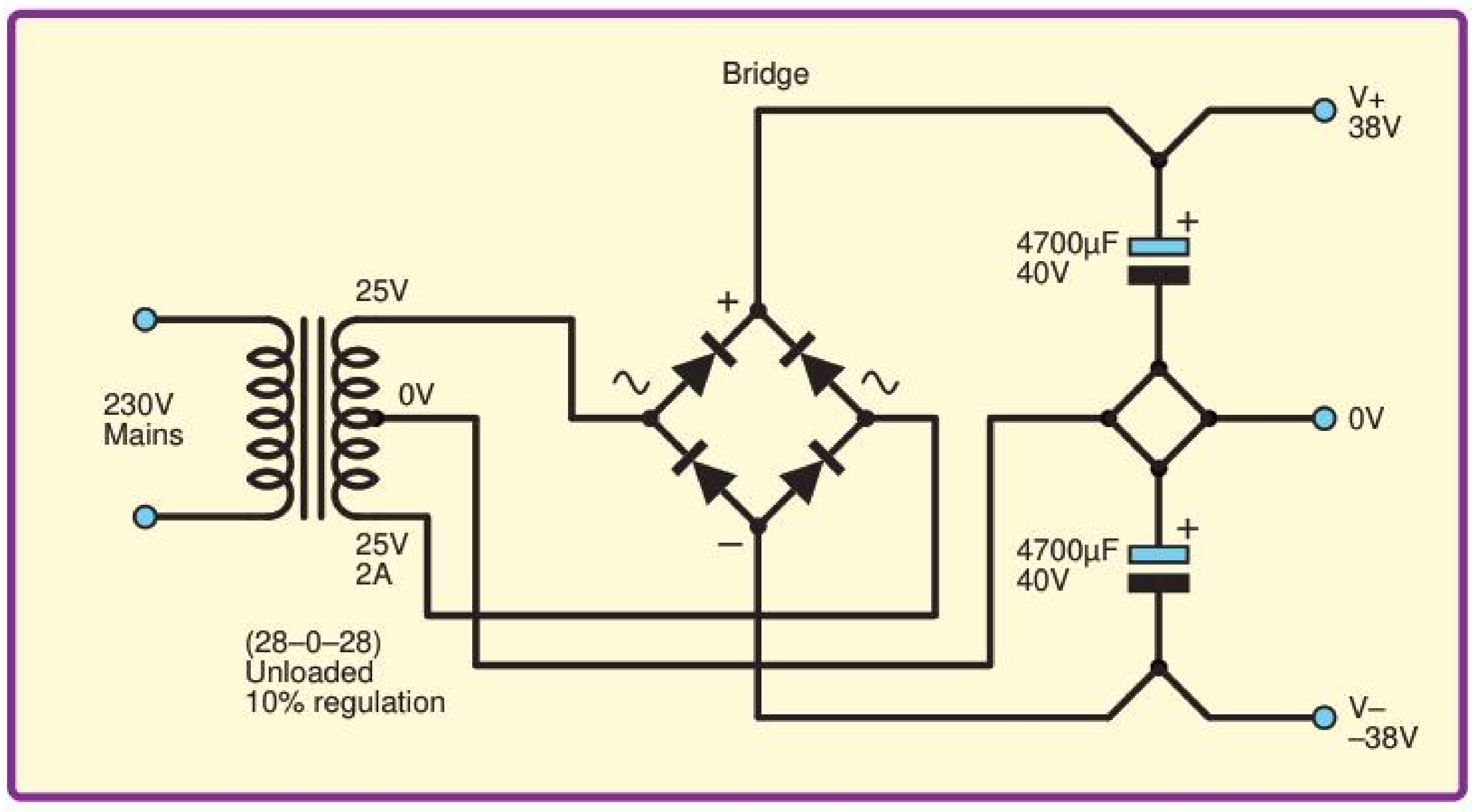

Fig.2. Standard unregulated audio power supply for typical 50W stereo amp. Output voltage is 1.4 times the unloaded secondary voltage – the rectifier drop. This voltage is held up for short music bursts, such as kick drums, if the capacitors are big enough. Note the noding on the capacitors

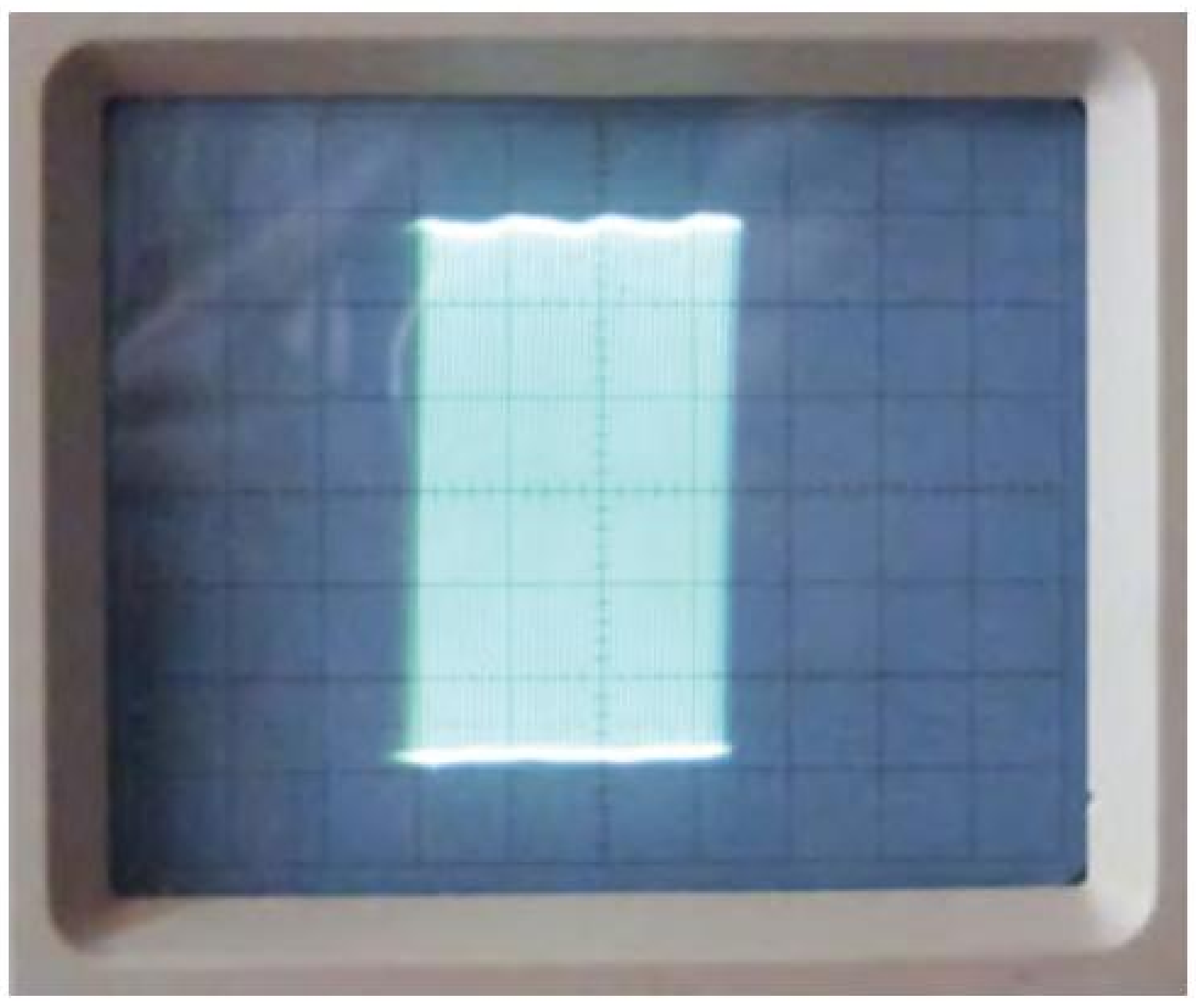

Fig.1. Power amplifier ripple breakthrough at clipping – note the 100Hz ripple riding on top of the clipped 1kHz sinewave

From a ripple point of view, the output stage almost acts as a voltage regulator, until the amplifier clips, where all control is lost. This 100Hz ripple breakthrough sounds horrendous because it intermodulates with the music – see Fig.1. Single-rail amplifiers only do this on the top of the output waveform, while dual-rail designs do it top and bottom. Most amplifiers have this horrid ripple effect, it just doesn't appear on the specifications. Clipping of Hi-Fi amplifiers should never happen in practice anyway. If you want to demonstrate it, feed a very high frequency that you can't hear (in my case 15kHz) and wind up its amplitude until clipping starts and you will hear the hum come in. (**Important: only do this on a high-power driver, such as a bass guitar speaker. Never do it on a Hi-Fi speaker, you'll destroy the tweeter.**)

A stabilised supply avoids this effect and results in less audible clipping with prolonged sounds. However, there will be at least a 20% power loss compared to the same mains transformer with an unstabilised supply. Another technique is to prevent the output stage from saturating by allowing the driver stage to clip first (fed from a filtered supply) but again, this causes significant output power reduction. This loss makes it difficult to market the product – why pay more for less power? Also, using a regulated power supply for a class-AB amplifier can occasionally lead to instabilities, if the amplifier feedback loop fights with the loop in the regulator. The loss of efficiency can be circumvented with the use of regulated switchmode power supplies, such as those marketed by Hypex, but with

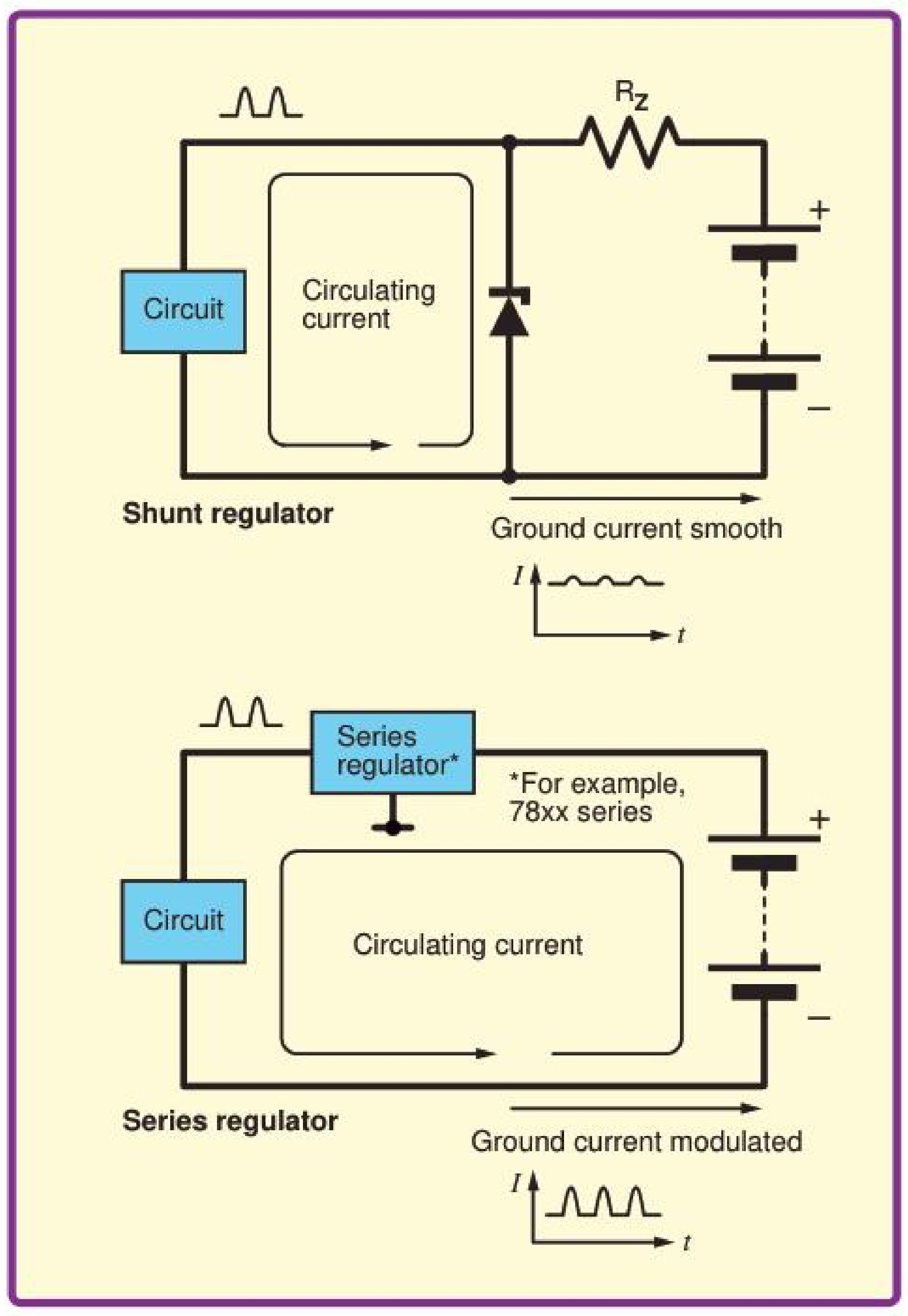

Fig.3. Shunt regulators keep the circulating currents local. Decoupling capacitors do the same thing at the higher frequencies

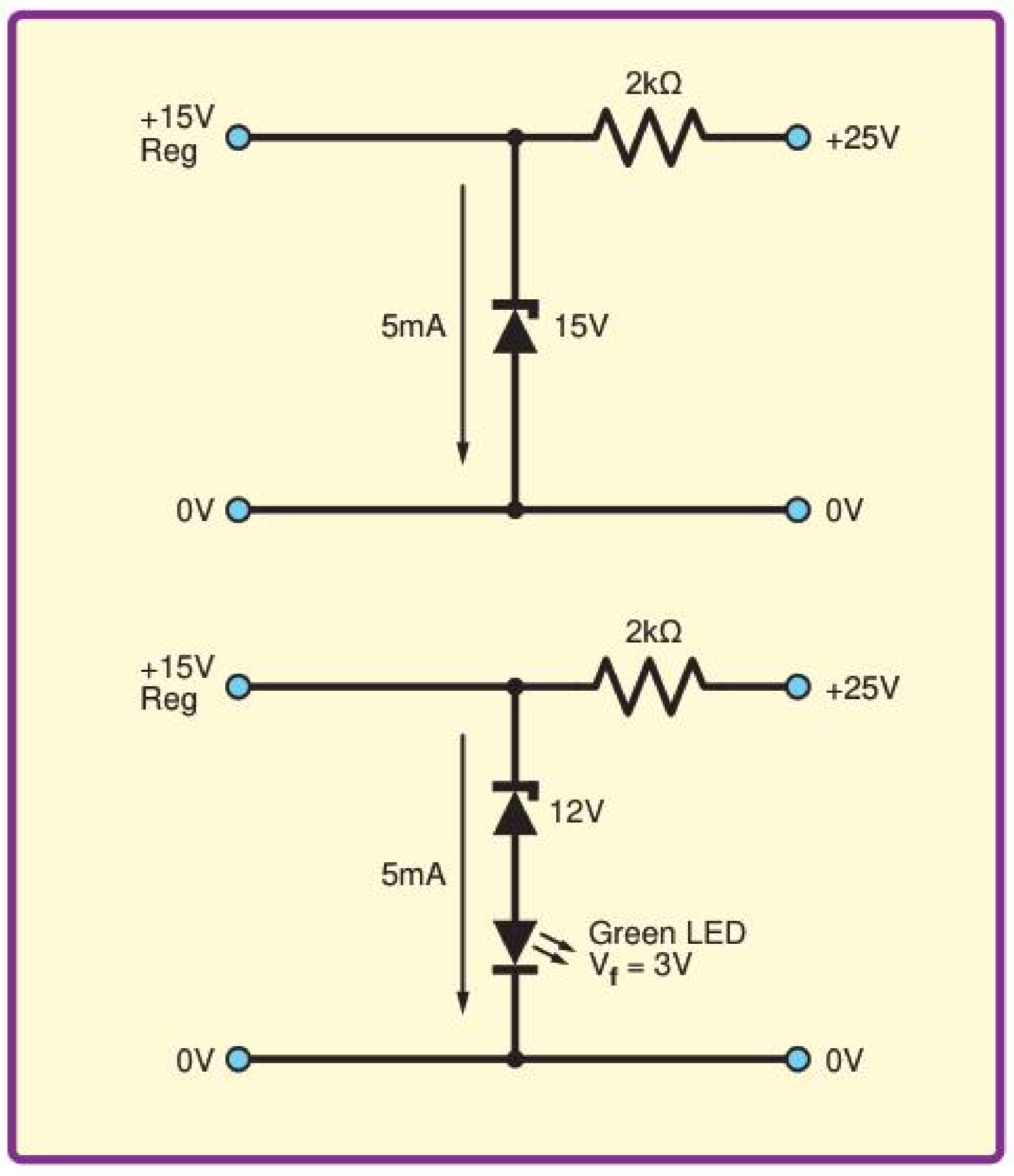

Fig.4. If you are going to use Zener diodes as voltage references then an LED can always be put in series to get a power-on indicator

typically 40 semiconductors and 20 electrolytic capacitors, their reliability is much worse than the standard linear unregulated circuit with basically just four parts, as shown in Fig.2. Note fusing is important to protect the expensive toroidal transformer which have non-resettable internal thermal fuses fitted to prevent fire. Switchmode power supplies can save money when manufactured in large quantities, but for small batch builders who cannot enjoy quantity discounts available on small components, using a toroidal transformer is cheaper.

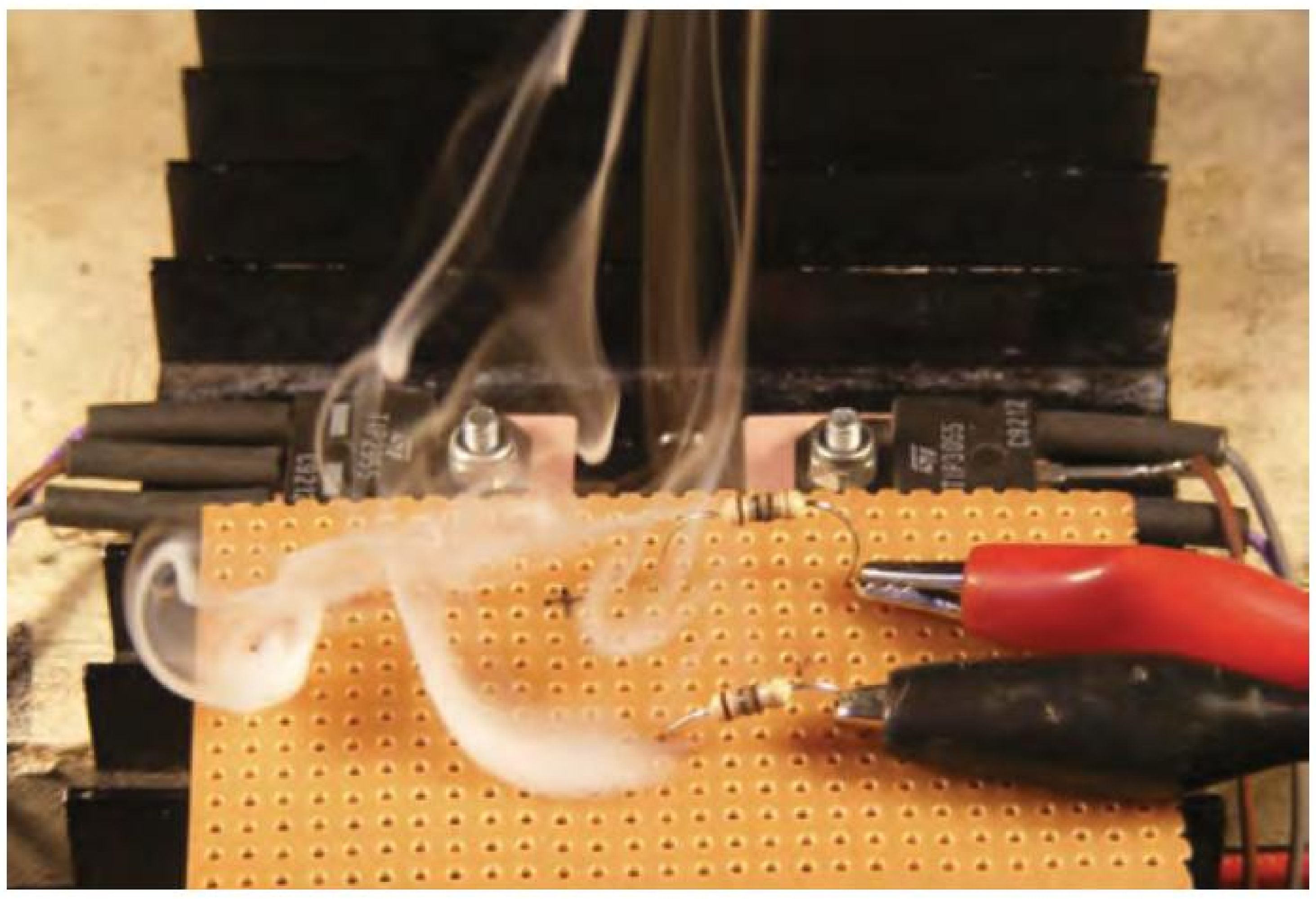

Fig.5. When testing power amplifiers put 100Ω resistors in series for the initial powering up. This provides simple protection, since there is no defined current limit with the standard unregulated power supplies. The resistors may go up in smoke if there's an error, but your output transistors won't! Alternatively use a proper dual ± 60V bench power supply with simultaneous shutdown if you are rich.

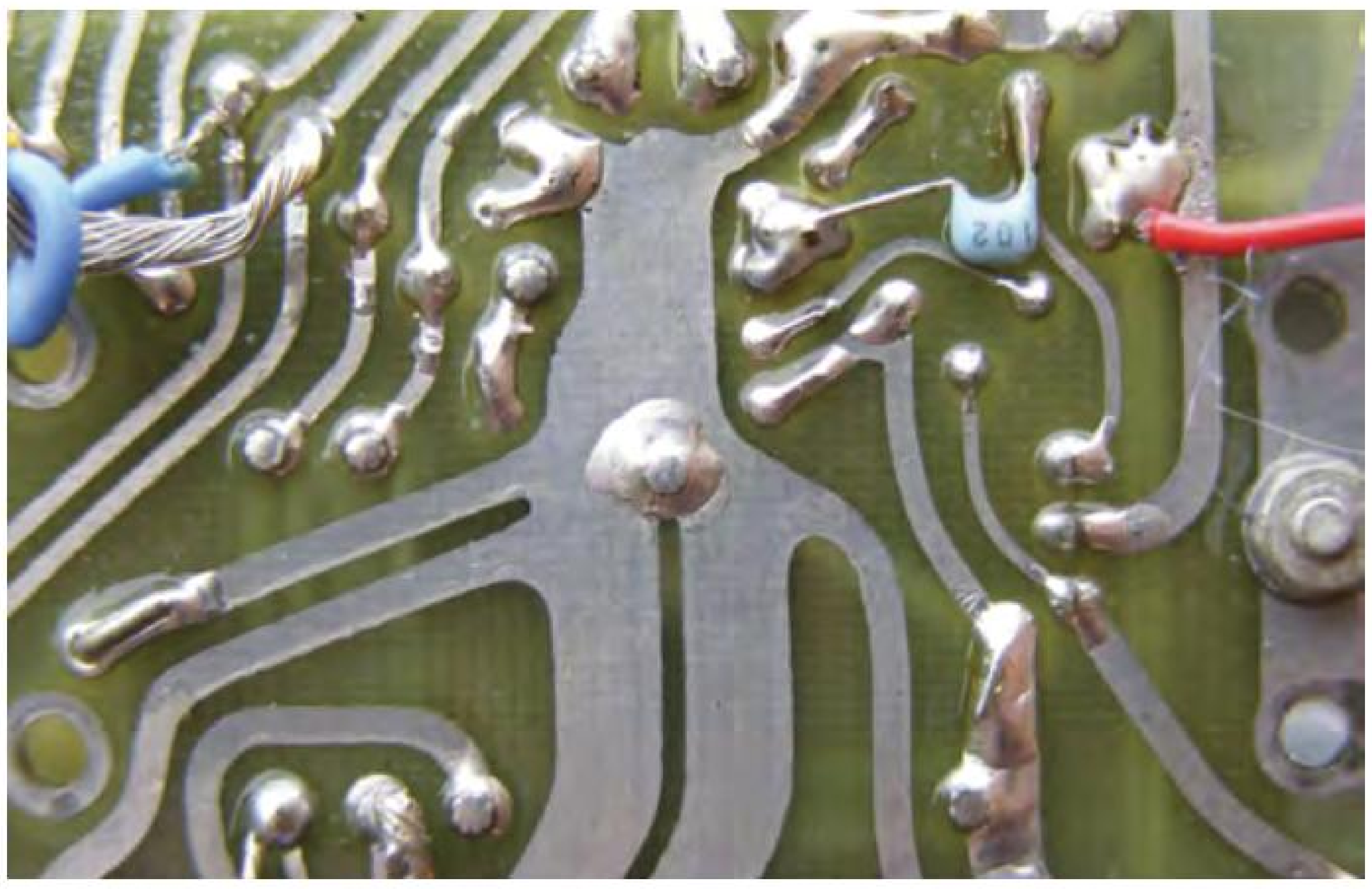

Fig.6. An earthing 'star' on a PCB is essential where all tracks have to be at the same potential

Bouncy power

There is an unexpected bonus with unstabilised power supplies – short-term peaks can be passed undistorted before the power rail sags, giving a higher perceived output. In my experience, a minimum of 2000µF of total capacitance per 10W of power output is required. This trick also allows the mains transformer to be undersized somewhat before sonic degradation with real music is evident. The same trick also applies to heatsink size. Of course the proviso with these 'consumer engineering' techniques is that prolonged full power sinewave tests must be avoided or meltdown will occur.

Shunt or series?

It is a popular belief in audio that shunt regulators are better than series because the circulating current is confined to a local loop, as shown in Fig.3. Of course, a decoupling capacitor will do the same thing down to a minimum frequency – but, a shunt regulator will work all the way down to DC. I use zener diodes across op amps for this, often with an LED in series to get 'free' light (see Fig.4). Look at the Peak ZEN50 review (*EPE*, Sep 2015) to see how LEDs can be used as reference diodes. Shunt regulators are inefficient, just like class-A amplifiers, the less output they are asked to deliver the hotter they get.

Burning resistors

All electronic engineers know that smell of burning resistors, the pungent odour of vaporised epoxy resin. It's also the smell of burning money. One thing I often do when powering up a power amplifier for the first time is use cheap resistors in the power rails for protection in addition to fuses. This is because there is no proper current limiting on typical unregulated audio power supplies.

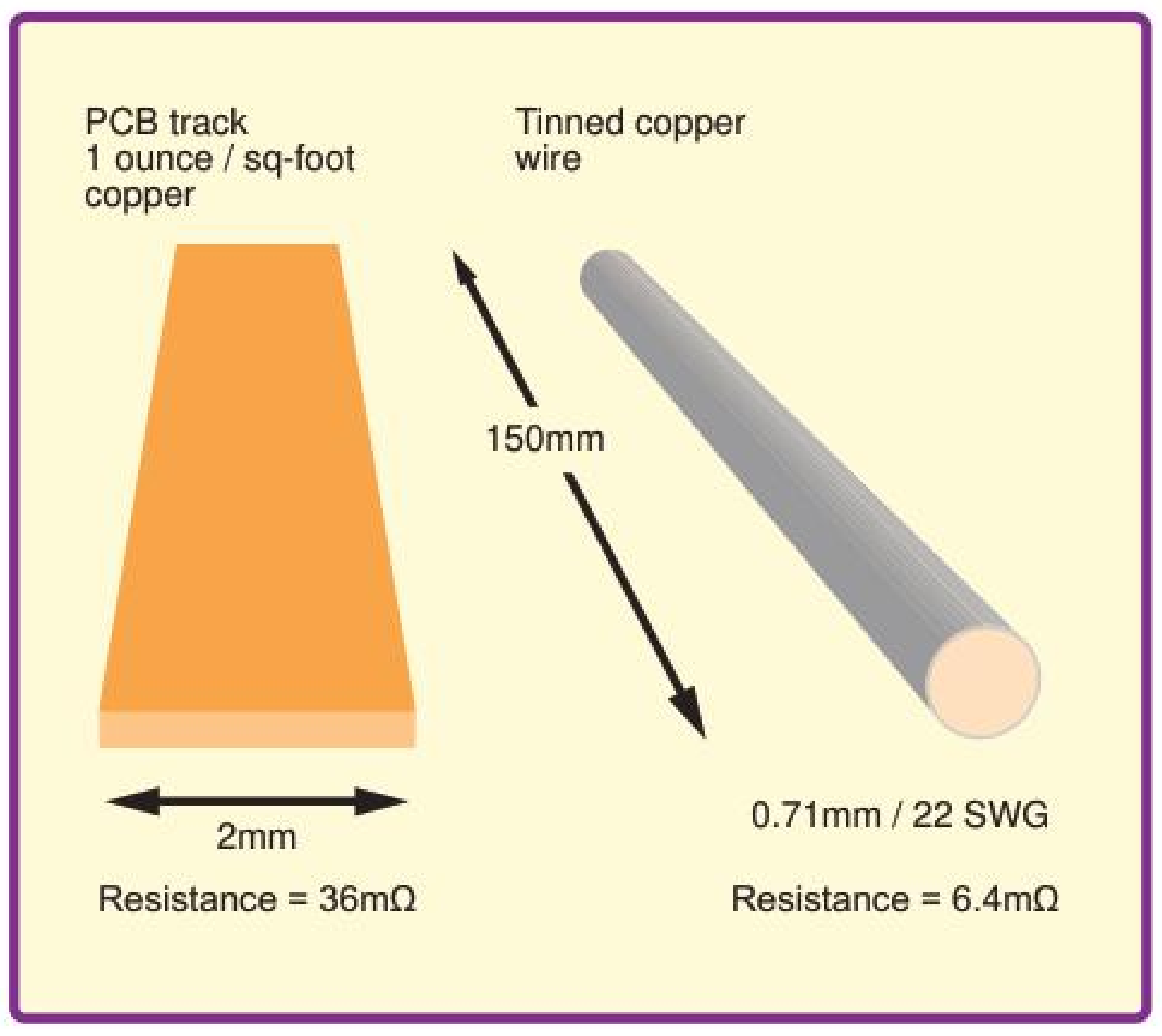

Fig.7. The resistance of PCB tracks is much higher than standard wire – in this example six-times more than comparable wire. The associated voltage drops cause problems with solid-state class AB amplifiers. Hard-wired valve amplifiers suffer much less

The destruction caused by a transistor inserted the wrong way or a PNP put in place of an NPN can be enormous. Another common error is the quiescent current preset set to maximum rather than minimum. I often solder the resistors – typically 47Ω to 100Ω – across the fuse holders (with no fuses in) since resistors are typically 20-times cheaper than fuses. Fig.5 shows an amplifier where a student got his TIP3055 mixed up with a TIP2955. Everything was fine in the end, apart from the resistors and the smell.

Voltage drops and starring

It's tempting when designing wiring or PCB layouts to forget that copper isn't a superconductor. I remember my early PCB designs where the earth track meandered around all over the board, naively believing it was all at 0V! Later on, my lecturer and mentor Tim Orr (of synth design fame) explained to me the technique of 'starring' or 'noding' where the connections are brought physically to one point (looking like a star, as shown in Fig.6.) so their potentials are equal.

Wiring resistance wasn't a problem with valve amplifiers because the load impedance is around a thousand-times higher, with a typical anode load of 4000Ω compared to a 4Ω loudspeaker in a solid-state amp. Currents are therefore a thousand-times lower. A 2mm-wide PCB track has a resistance six-times higher than the same length of 22 SWG wire, typically used in hard-wired valve construction (Fig.7). (0.036Ω, as opposed to 0.0064Ω). Thus, the associated voltage drops are typically 6000-times higher. I think this is one reason solid-state amplifiers can sound inferior to valve. It also explains why PCB production versions often don't sound as good as an original hard-wired lashed prototype. I often say to home constructors of audio it is a privilege to

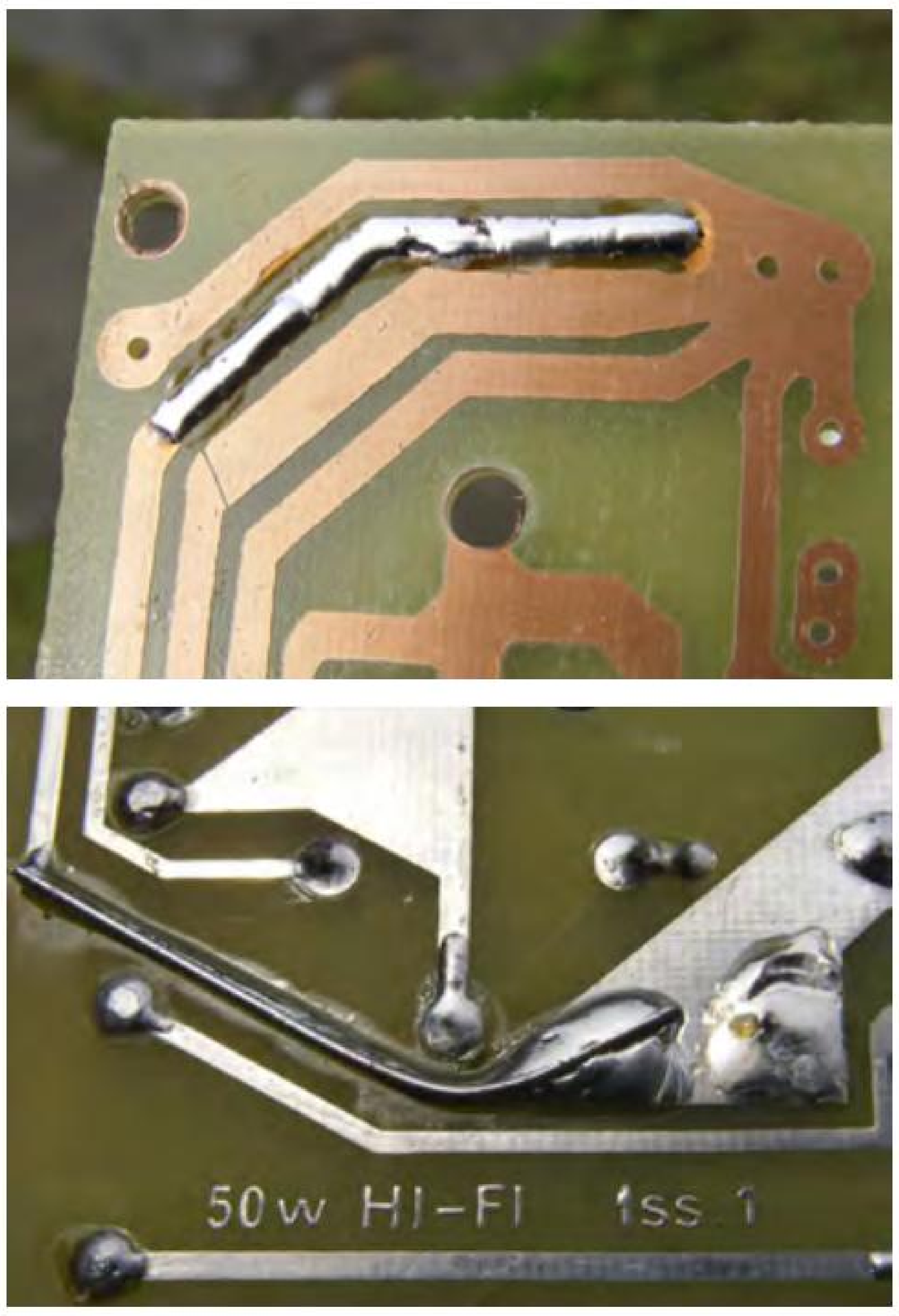

Fig.8 a) (top) Coating PCB tracks with a thick layer of solder halves the resistance.
b) (bottom) Soldering wire on top reduces it further still. I see this as a noise fixing dodge all the time in computer power supplies

50w HI-FI iss 1

be able to hard wire their own equipment. It's strange how audio is full of 'sub-prime' science and yet Ohm's law is often forgotten. Recently, I designed an active loudspeaker that used a single-sided PCB. I deliberately used some wire links instead of tracks to minimise voltage drops. A trick often used to fix high resistance PCB tracks is to coat the track with a thick layer of solder, as shown in Fig.8a, which reduces the resistance by half for standard 1oz copper boards. Also, soldering tinned copper wire along the track, as shown in Fig.8b provides a much bigger resistance reduction (approx. x5).

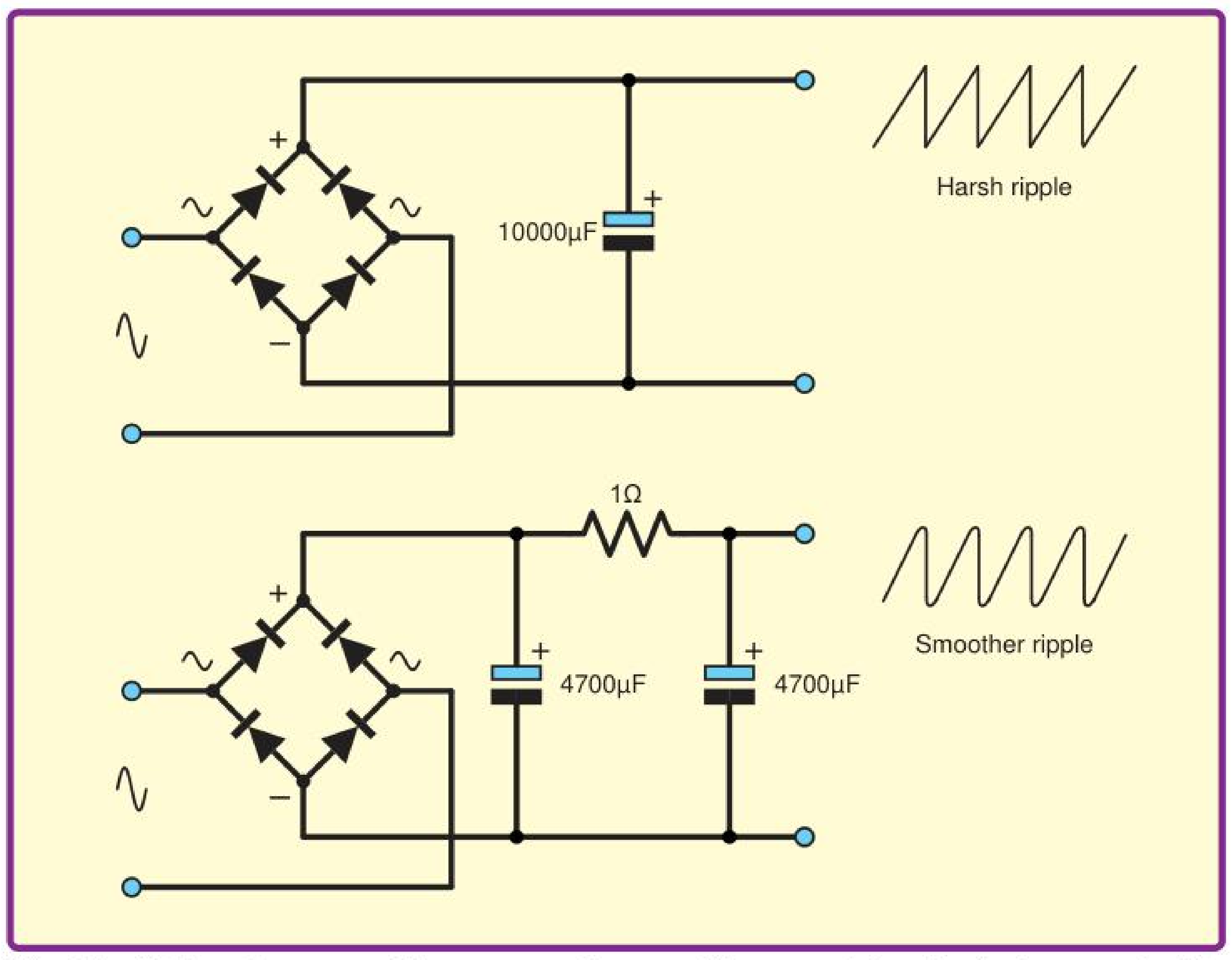

Fig.11. Using two smaller capacitors with a resistor in-between in the classic pi-filter layout results in lower harmonic ripple in the waveform. It is much easier for the amplifier to reject since its PSRR falls with frequency

+
~
~
–
∿
10000µF
+
Harsh ripple
1Ω
+
~
~
–
∿
+
4700µF
+
4700µF
Smoother ripple

Charging pulses

To prevent buzzy hum harmonics, care has to be taken to avoid the charging pulses from the rectifier impinging on the audio. The tracks from the output of the rectifier must go directly to the smoothing capacitor terminals. There will be high voltage spikes on these tracks, so nothing else must be connected to them. A short extension from the pins on the capacitor becomes the nodes from which the amplifier power lines are connected. This is shown in Fig.9 for a single-rail power supply. Fig.10 shows a suitable PCB layout. I still see buzzy amplifiers caused by power and earths connected to the rectifier feed tracks.

Hum

Most unregulated power supplies have just one smoothing capacitor per rail. It's worth using the old trick of adding a small resistor, say 0.22Ω to 1Ω and two smaller capacitors in a pi-filter configuration, shown in Fig.11. This gives a more rounded output ripple saw tooth waveform with less harmonics, which is less likely to couple into the sensitive audio circuitry (see Fig.12a and 12b). It can also save money by allowing two wire-ended caps to be used rather than a pricier tag type. Of course, voltage regulation is impaired to a degree. Bypassing the resistor with a diode can be used to limit the voltage drop to 0.7V. However, the harsh hum comes back when the diode conducts on peaks.

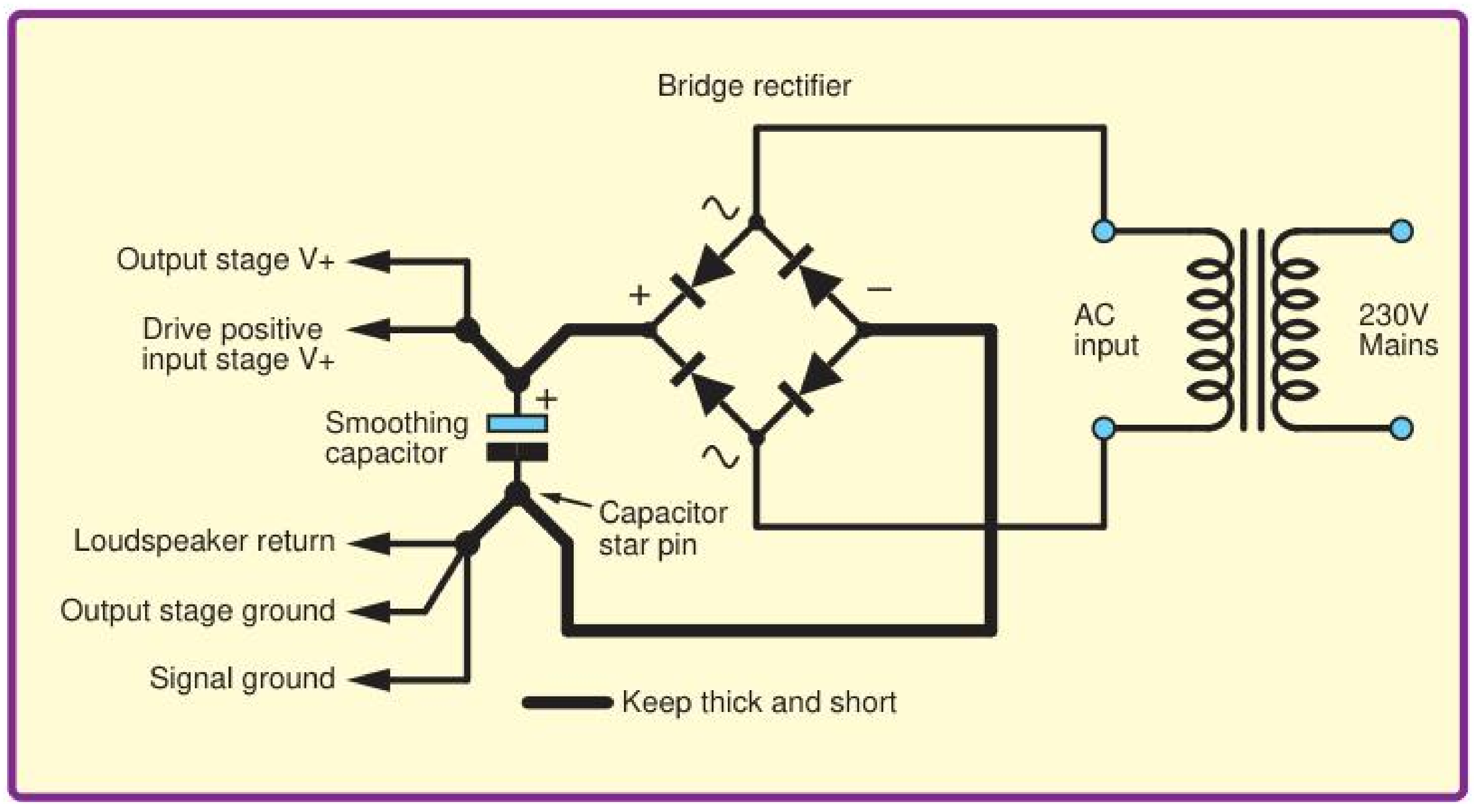

Fig.9. Correct wiring layout for a single-rail power supply

Bridge rectifier
~
+
–
~
Output stage V+
Drive positive input stage V+
+
Smoothing capacitor
Capacitor star pin
Loudspeaker return
Output stage ground
Signal ground
Keep thick and short
AC input
230V Mains

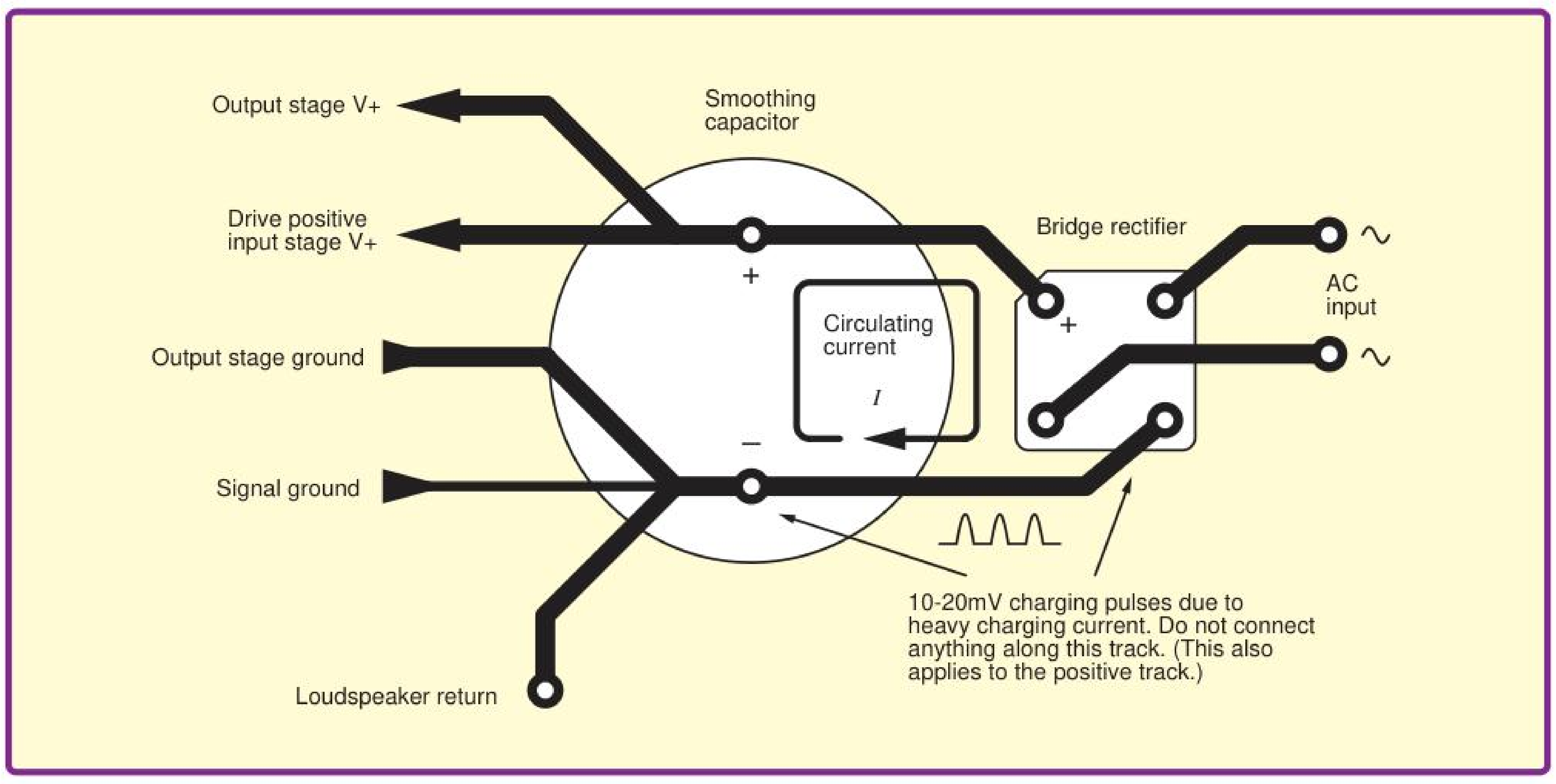

Fig.10. Correct PCB noding to avoid buzz – incorrect connection to the track carrying the charging current can induce spiky charging pulses into the amplifier

Output stage V+
Smoothing capacitor
Drive positive input stage V+
+
Bridge rectifier
~
+
AC input
~
Circulating current
I
Output stage ground
–
Signal ground
10-20mV charging pulses due to heavy charging current. Do not connect anything along this track. (This also applies to the positive track.)
Loudspeaker return

Next month

In *Part 2*, next month I will move on to look at speaker return currents, power-rail-induced distortion and decoupling capacitors.

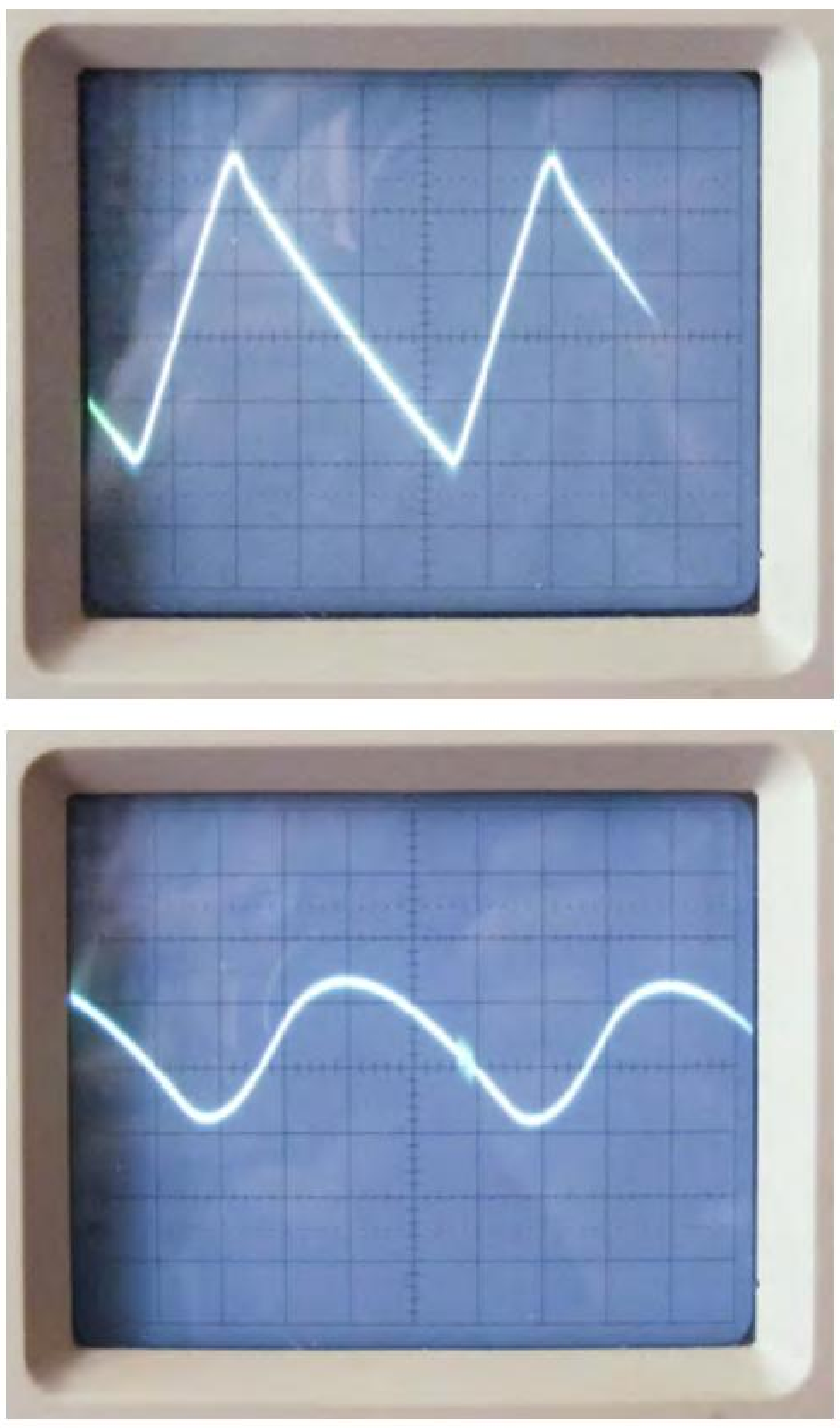

Fig.12 a) (top) Sawtooth ripple waveform of single capacitor. b) (bottom) Note more rounded edge from splitting the capacitor and adding a resistor

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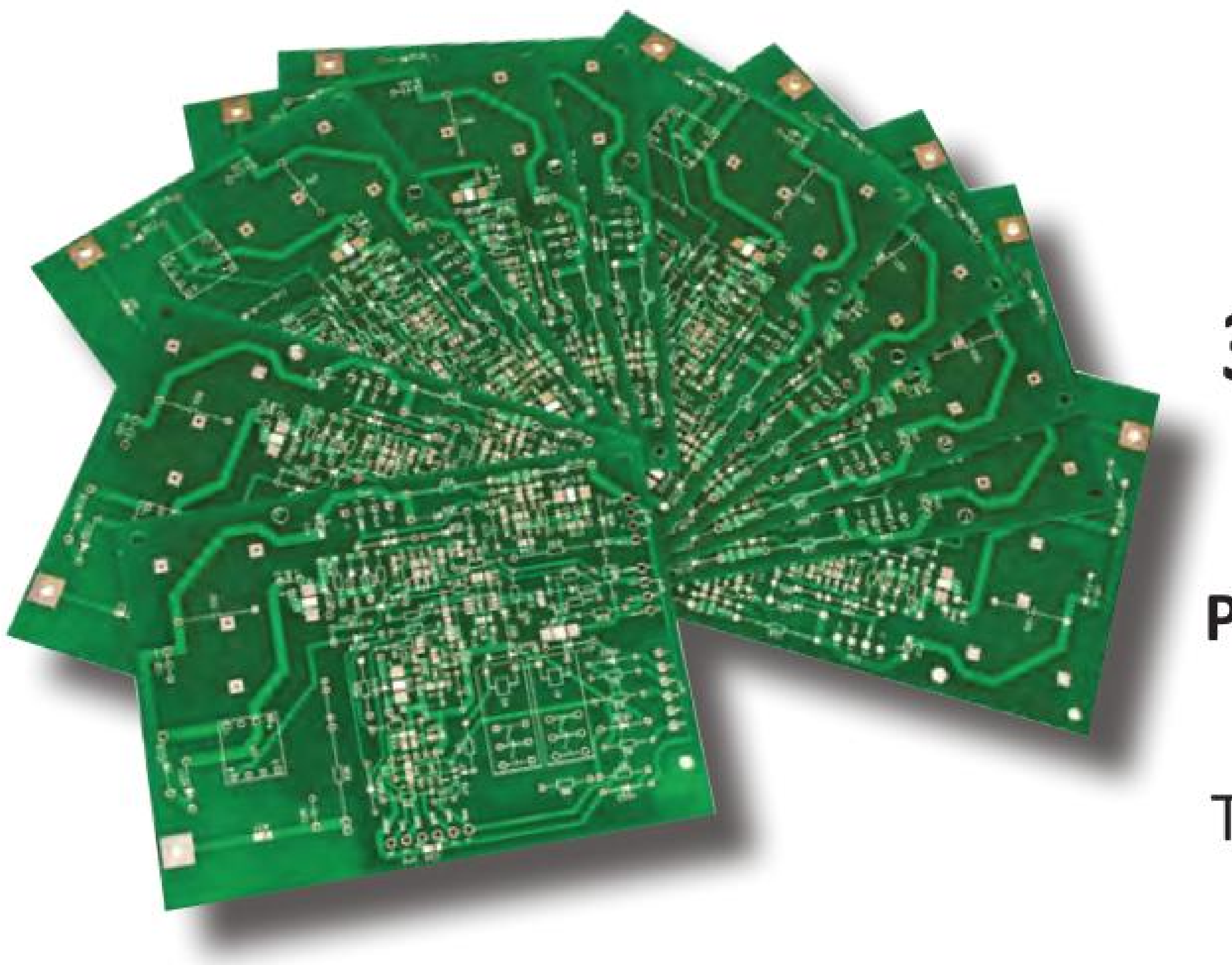

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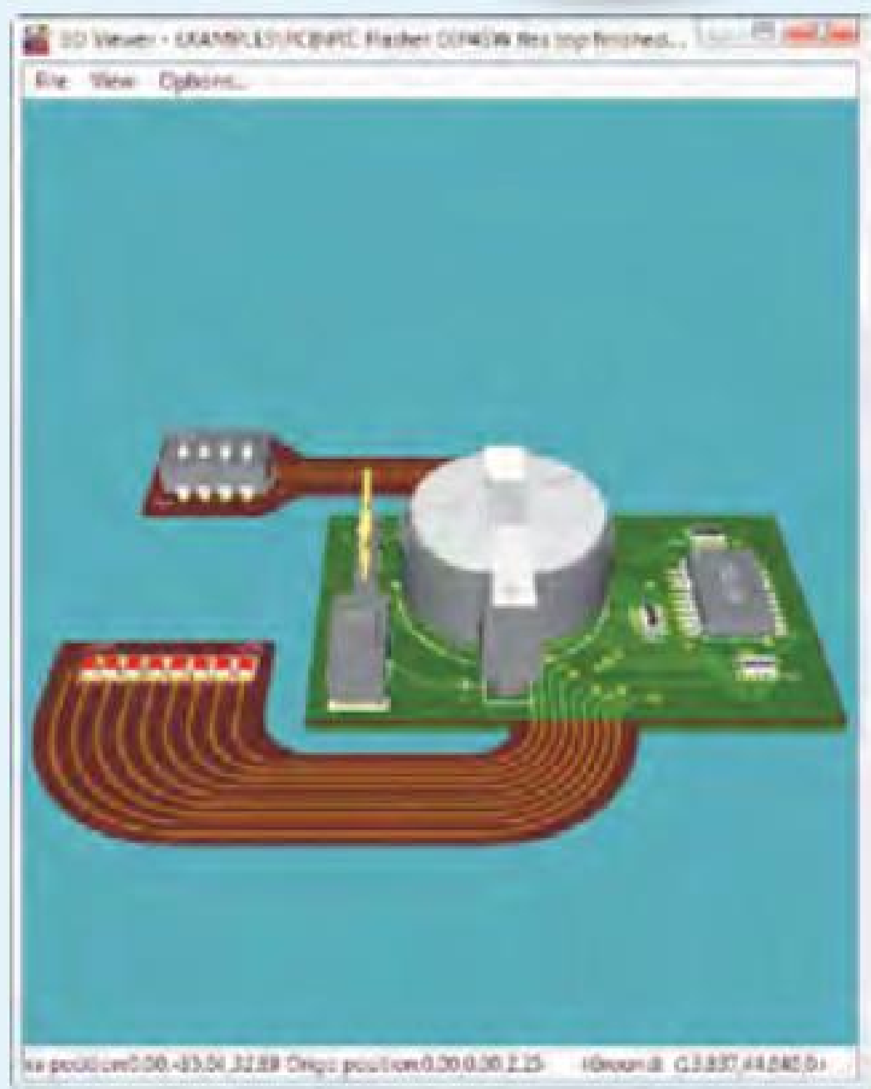

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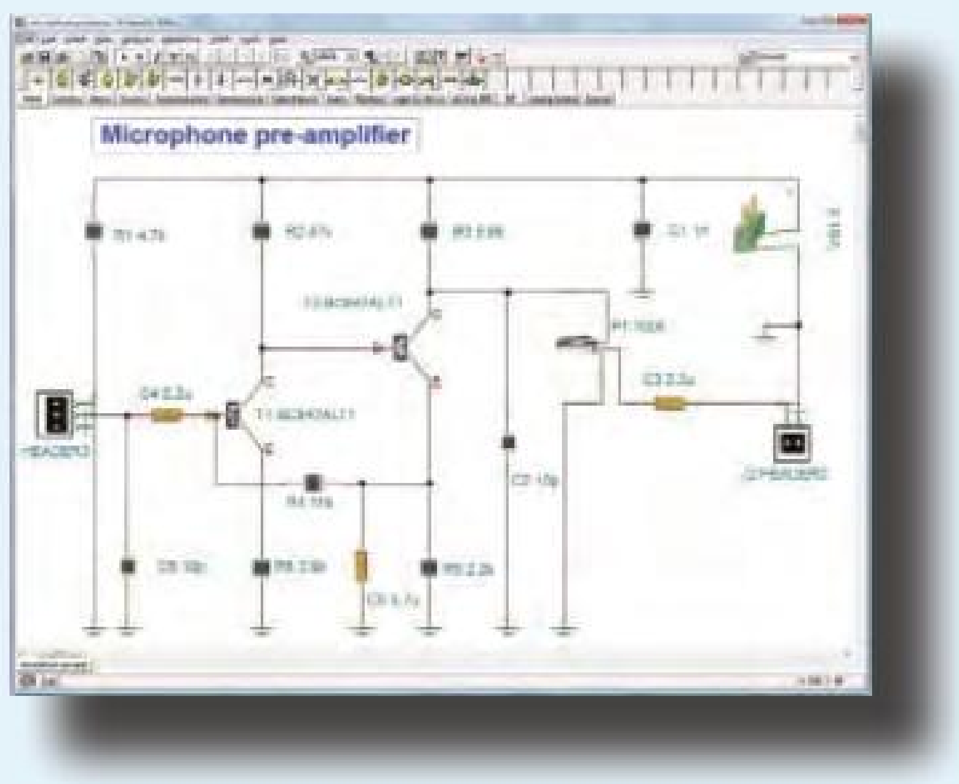

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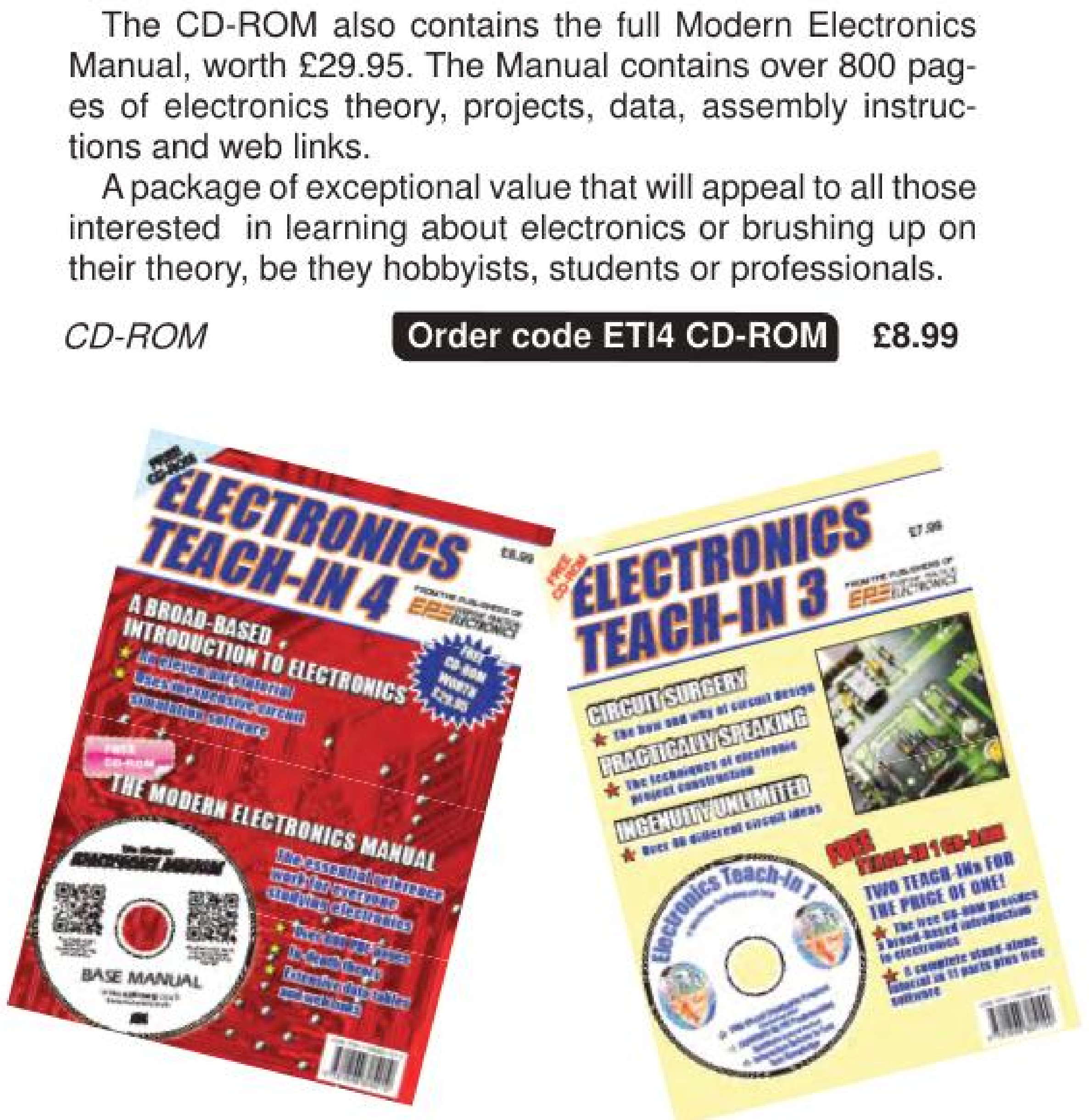

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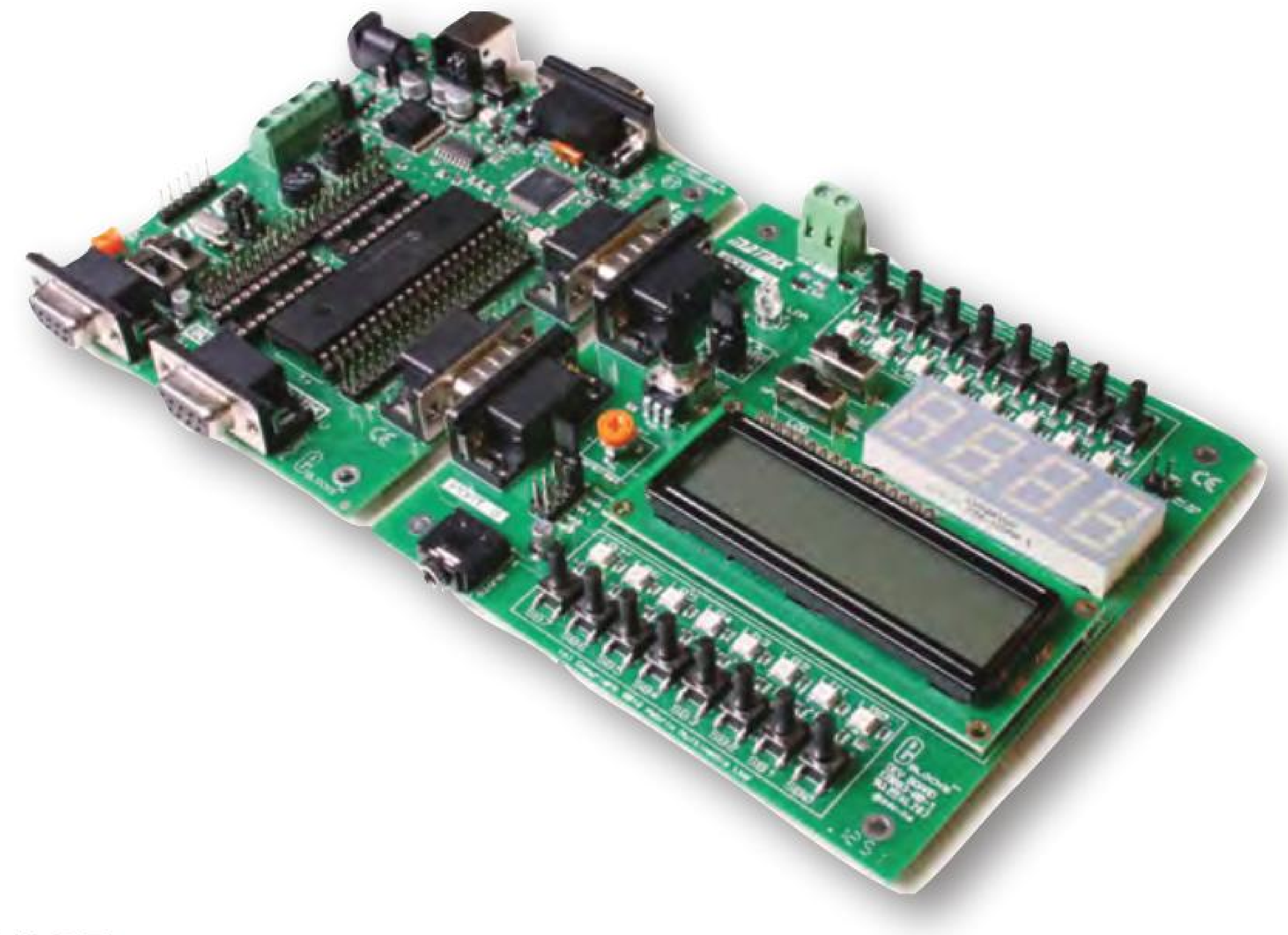

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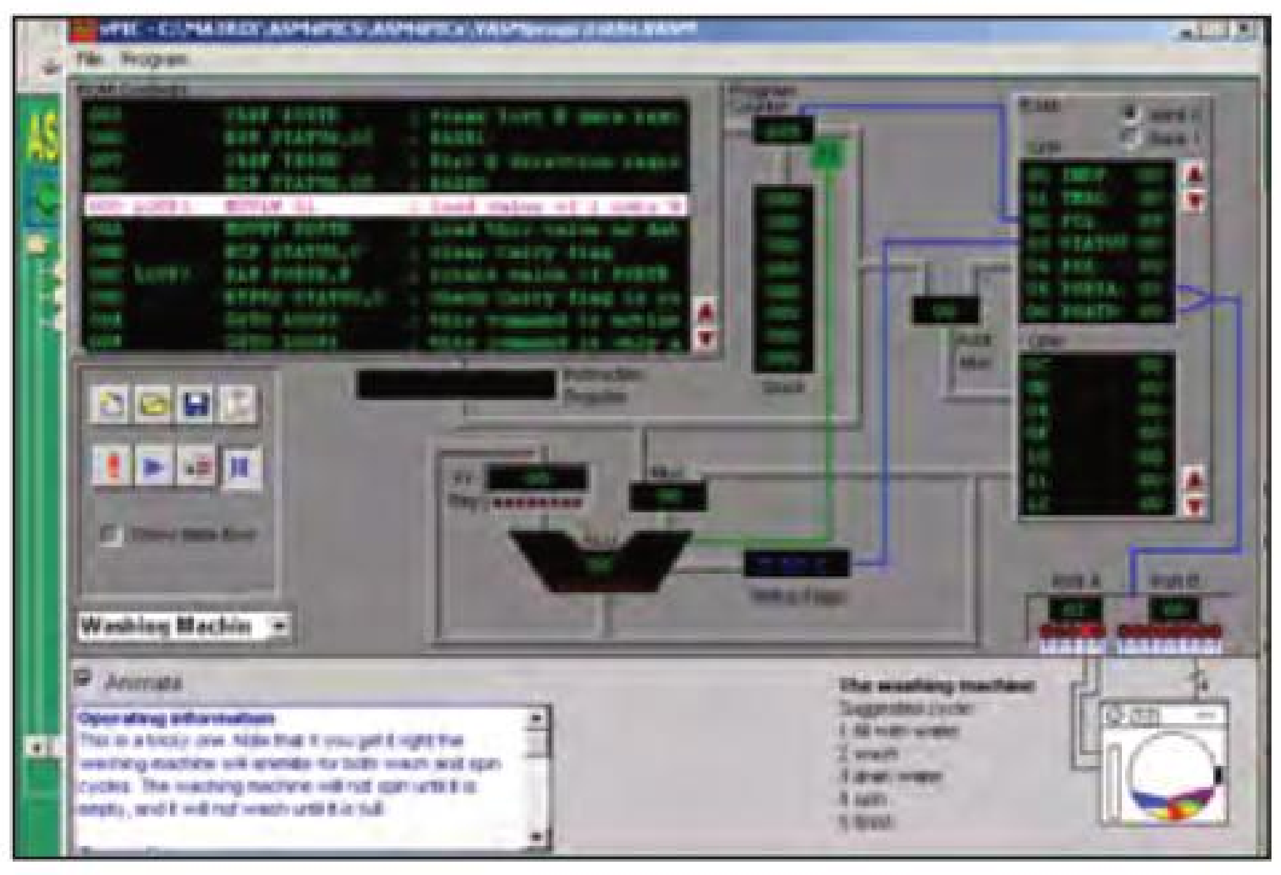

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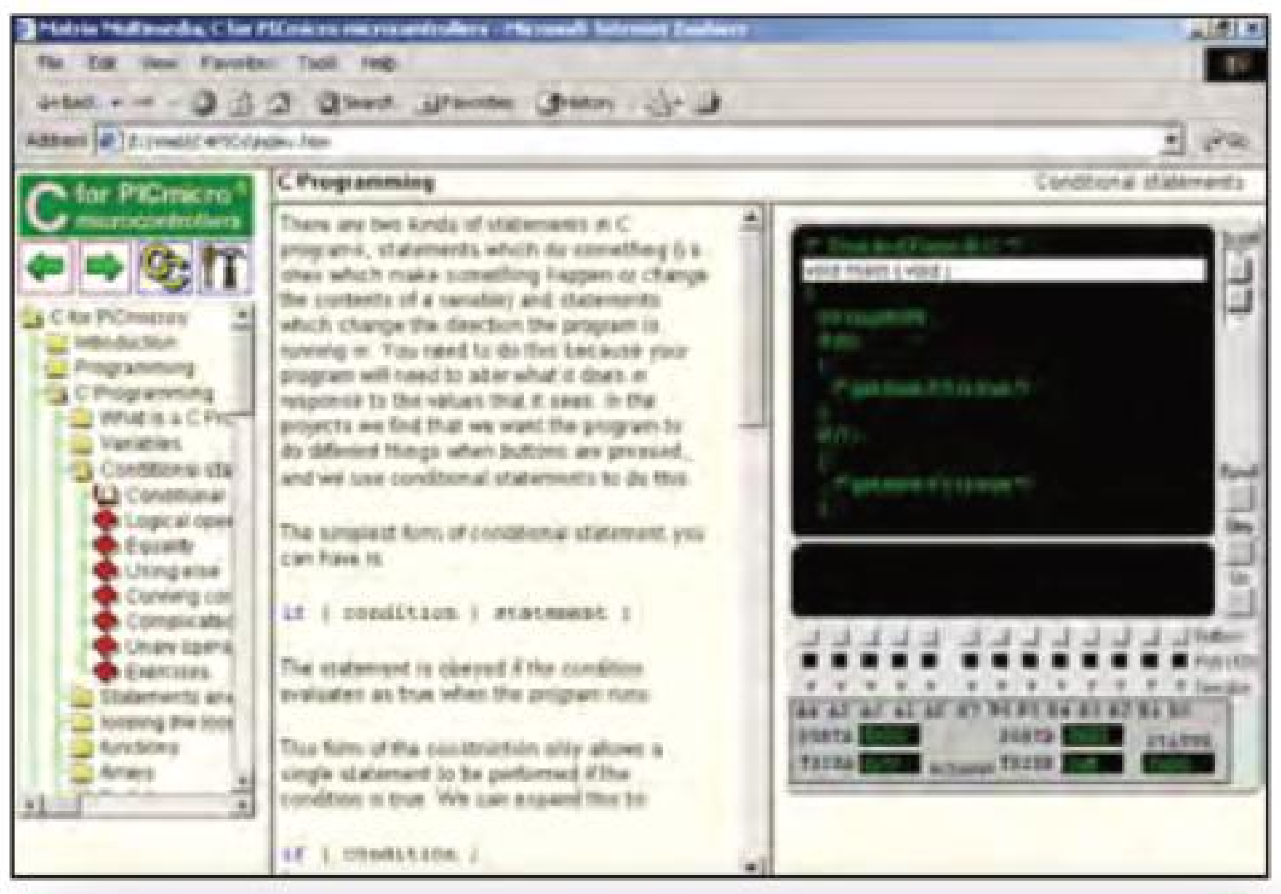

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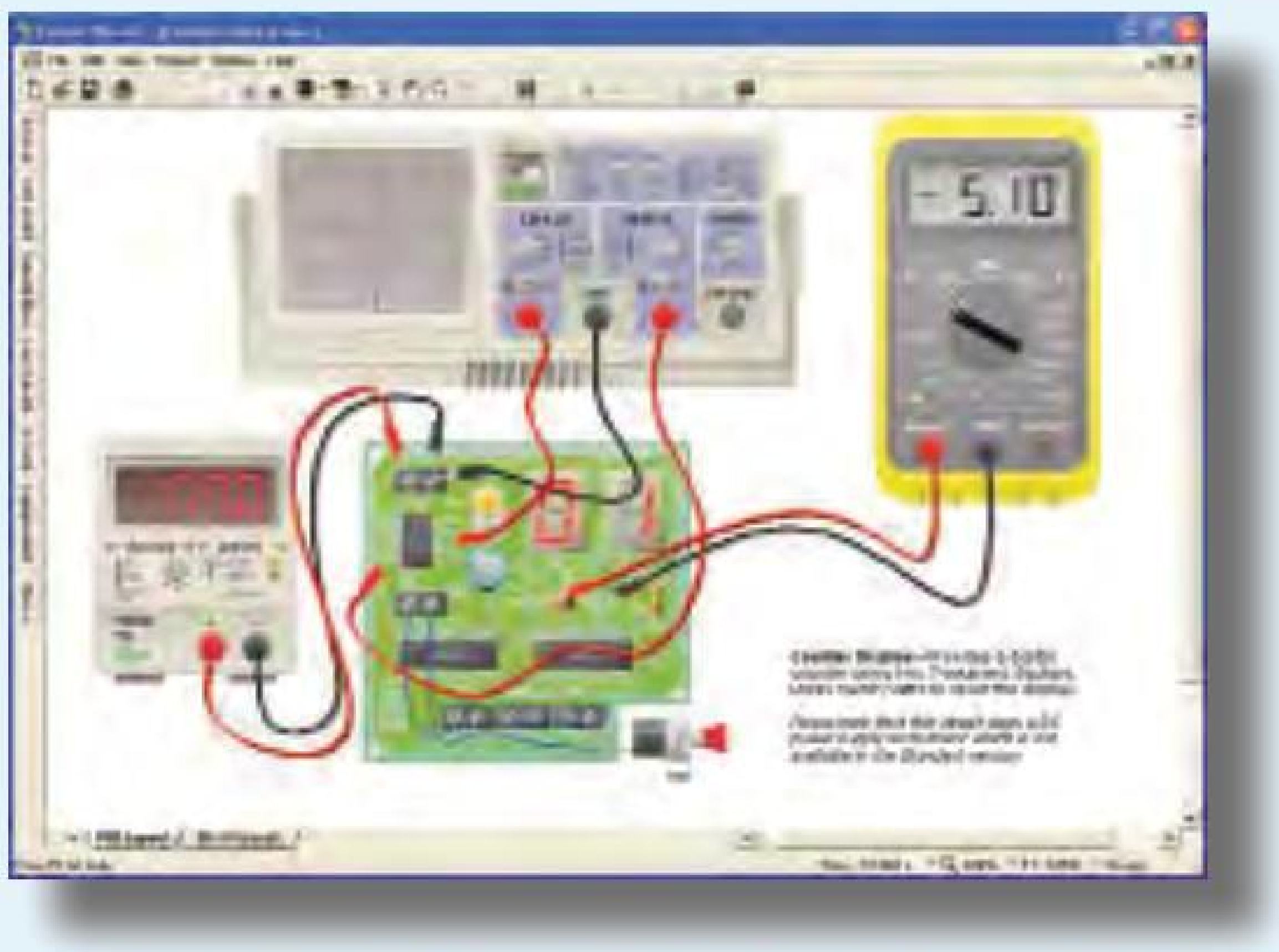

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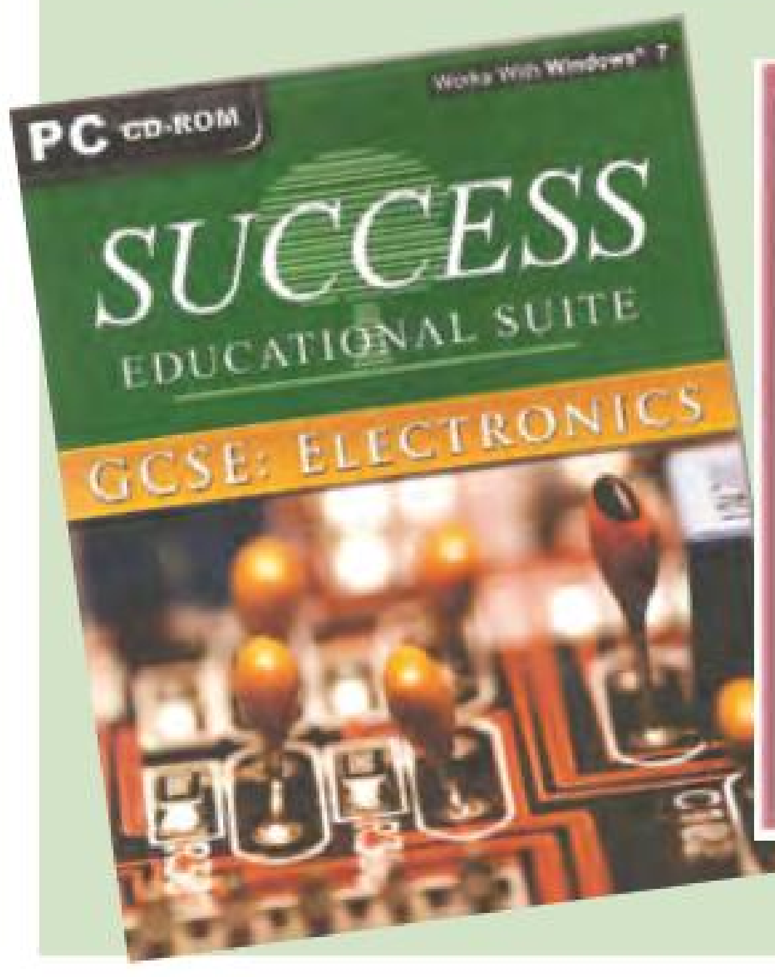

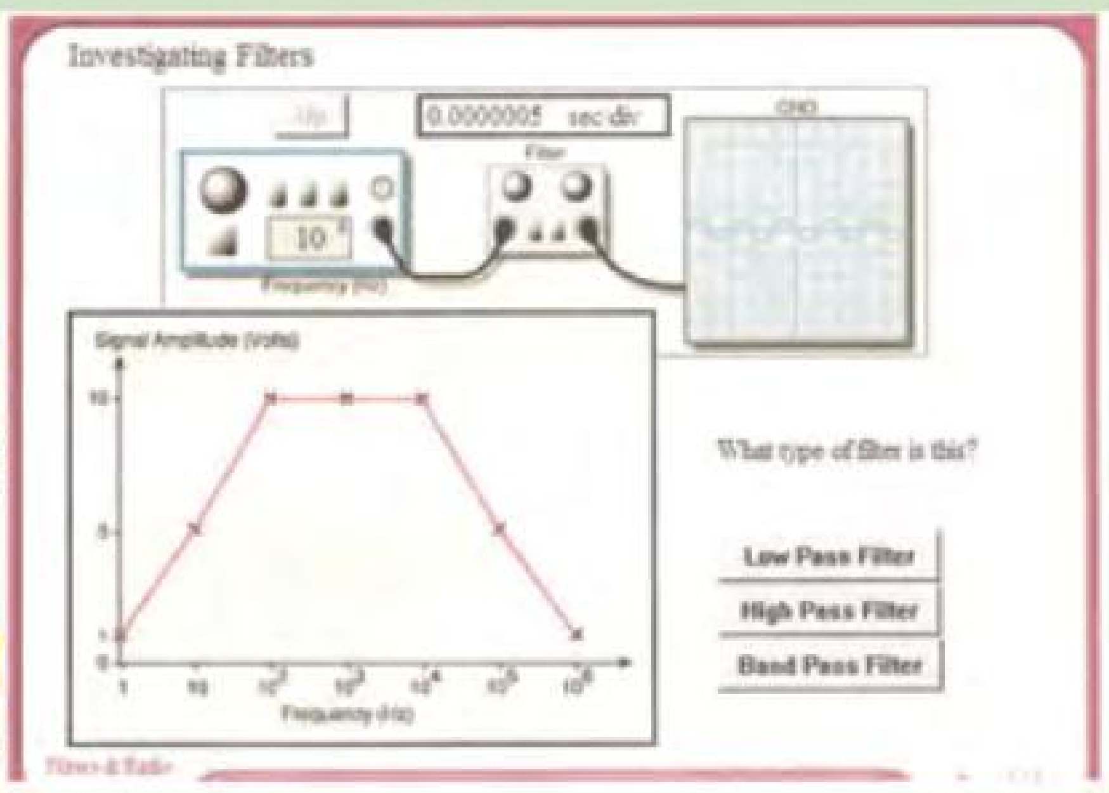

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Max's Hot Beans

By Max The Magnificent

High-end VR

In my previous column, we considered some of the starter virtual reality (VR) systems that are available, including Google Cardboard (**http://amzn.to/2ckcjTK**), Gear VR (**http://amzn.to/2bWdeJ6**), and VR Box (**http://amzn.to/2bWeAmQ**). Another low-end system that has just joined the fray – literally as I'm penning these words – is Google's Daydream View, which people are calling 'The VR headset for everyone else.'

In the same way that Gear VR works with Samsung's smartphones, Daydream View is designed to play with Google's Pixel smartphones or other Daydream-compatible devices. First reports say that the Daydream View is extremely comfortable, it looks stylish, it accommodates people wearing even large glasses, and it comes with a motion-sensing wand (unlike the Gear VR's mega-awkward integral controls).

If you want to move upmarket, the next port of call has to be the PlayStation VR (PSVR), which will be available for purchase by the time this column hits the streets. At $399, the PSVR isn't cheap, but it storms past it's lower-end counterparts in terms of its capabilities. Of course you will also need a PlayStation 4 (PS4) console, plus you will want to invest in motion-tracking Move controllers and a PlayStation Camera, which are sold separately.

I'm actually quite surprised to hear that the PSVR can be driven by the PS4, which was never really intended to provide this amount of computational horsepower. Thus, many users will probably want to upgrade to the PS4 Pro with its significantly faster processor and much higher graphics processing capability (the PS4 Pro should be available in time for Christmas).

Although the PSVR won't be able to compete with top-of-the-line VR headsets with regard to their state-of-the-art graphics capabilities, it will almost certainly storm ahead in terms of content in the form of Triple-A rated games.

Crème de la crème

The current high-end in virtual reality is dominated by two players – the Oculus Rift, which costs around $599 (**http://ocul.us/29N3geD**), and the HTC Vive, which will set you back around $799 (**http://bit.ly/1ZOZzGR**). On top of the upfront purchase price, both of these devices also require an equivalent high-end processor-graphics combo to drive them. Depending on what you put in it, you can expect to pay anywhere from $2,000 to $4,000 for a tower computer (serious gamers might pay $10,000 and up).

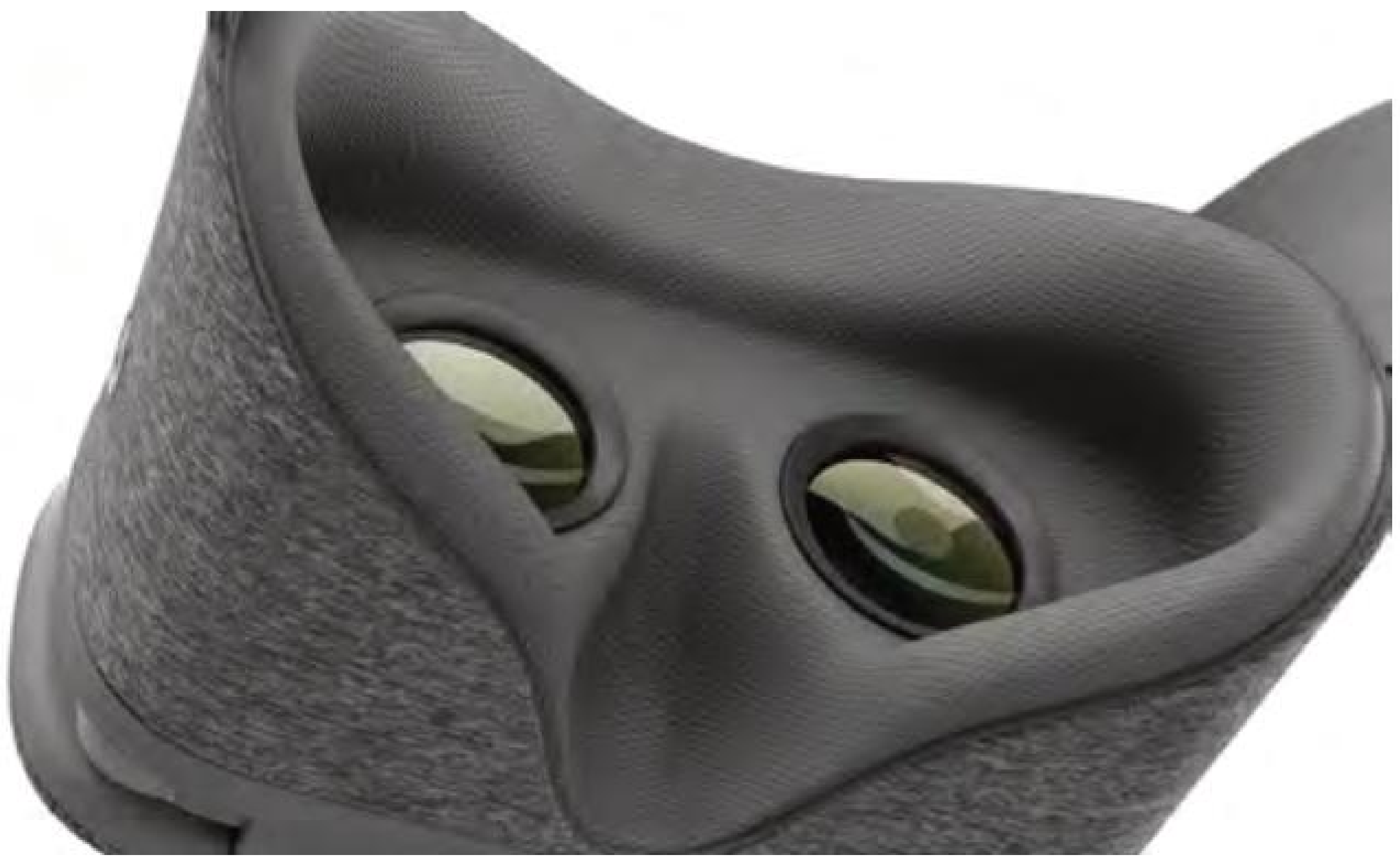

Fig.1. Google's newly minted Daydream View, designed to play with their Pixel smartphone

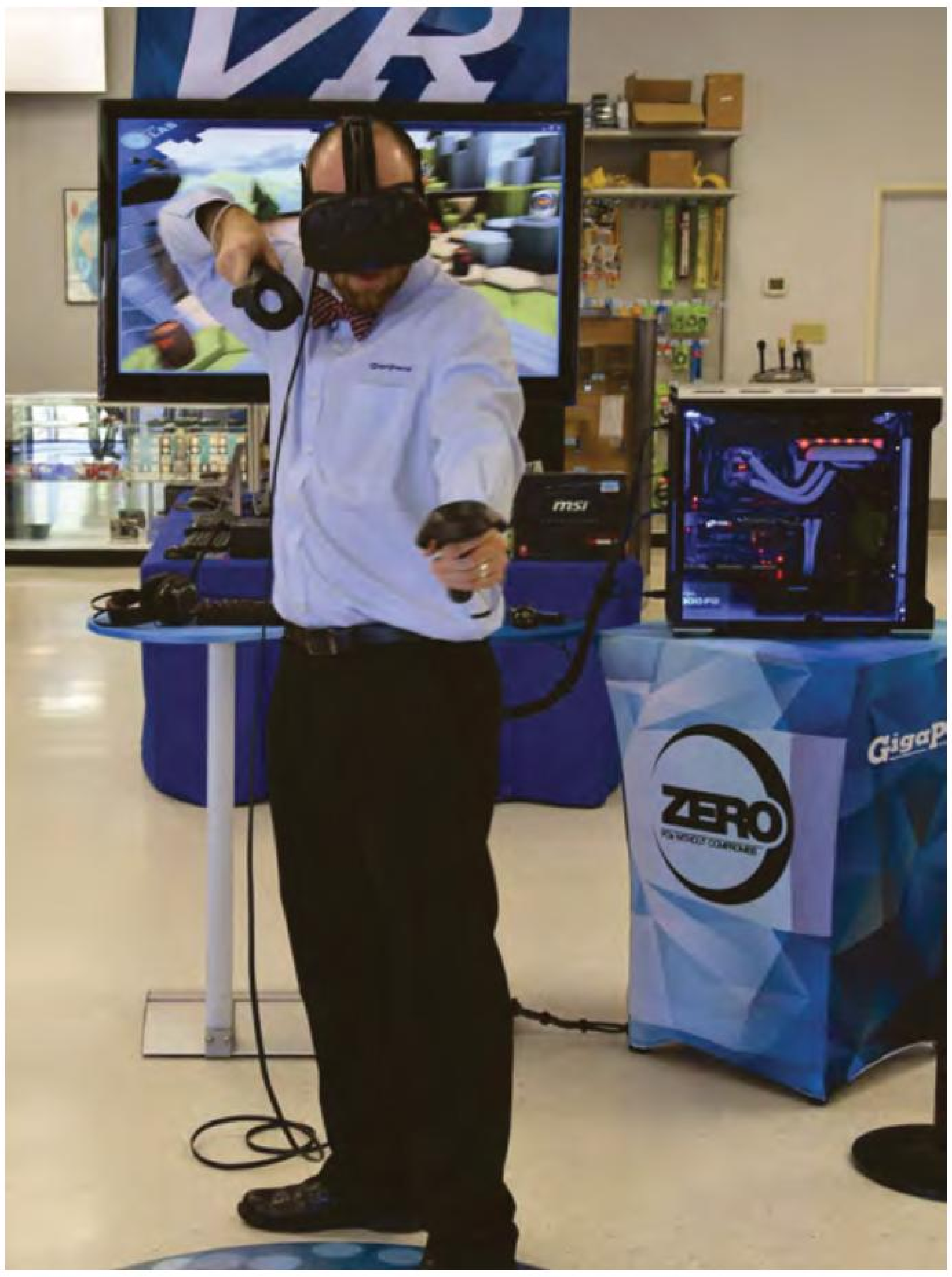

Fig.2. One of the guys at GigaParts playing with an HTC Vive

Until recently, it wasn't possible to find a notepad (laptop) computer capable of driving these high-end VR headsets, but these machines are starting to appear on the market. For example, I just invested in a rather tasty laptop from the folks at MSI (**http://bit.ly/24gmxGZ**). This little scamp sports a 6th Generation Intel Core i7 with four cores and eight threads, 32GB of RAM, a 512GB SSD for the system and applications, a 1TB HDD for data, and a 120Hz refresh-rate display (typical computer displays use a 60Hz refresh rate). All of this is complemented by an NVIDIA GeForce GTX 1080 graphics subsystem to drive my Oculus Rift.

Rift vs Vive

So, if you are thinking about taking the plunge and purchasing a high-end VR headset, which one should you choose – an Oculus Rift or an HTC Vive? This really is a tricky one. I visited my chums at GigaParts, where they have a VR demo area set up for folks to try different headsets, and I gave them both a whirl.

The Vive is a tad ‘bulkier’, but it does better accommodate users wearing glasses (I have to wear an older, smaller pair with my Rift). Both the Rift and the Vive provide a resolution of 1,080 × 1,200 per eye (as compared to 960 × 1080 for the PSVR).

One area where the Vive really scores is that it comes equipped with two controllers that are tracked by the system and that appear in the virtual world with you. Also, the Vive comes equipped with two sensors, which allow you to roam around a 15 × 15-foot tracking area. By comparison, the first generation of the Rift ships with a single sensor and an Xbox controller, and it supports a tracking area of only 5 × 11 feet. Having said this, the folks at Oculus are poised to release their Touch controllers, which – according to early users – are incredibly ergonomic and easy to use. These controllers will come with a second sensor, which will increase the size of the Rift’s tracking area to be comparable with the Vive.

There’s also the case that different games and applications are available on the different headsets, with some amount of overlap. This was the deciding factor for me, because the reason I got into all of this in the first place was Cyan’s Obduction game (**http://bit.ly/1Ry4S7g**), which is targeted at the Oculus Rift. At the end of the day, I would say to try both the Oculus Rift and the HTC Vive and to pick the one that best-suits you in terms of comfort and application support.

And what of the future?

The main thing to remember is that we are only just dipping our toes in the virtual and augmented reality waters. Just a year ago, pretty much the only game in town was Google Cardboard. Now, new VR headsets are appearing almost on a daily basis.

There are so many possibilities for the future that it makes your head spin. One option is to equip the headset with infrared illumination and two forward-facing cameras that can track the user’s hands and add virtual representations of them into the virtual world, potentially removing the need for special controllers. Another possibility is to use the same forward-facing cameras as the basis for an augmented reality system, in which textual data and graphics are overlaid on one’s view of the real world.

Yet another option is to equip the headsets with eye-tracking capabilities. Since the human optical system only sees a very small area in focus, this would allow the graphics subsystem to only have to render a small area at high-resolution, with peripheral areas being progressively more blurred. In turn, this would dramatically reduce the amount of processing power required to render the scene and the amount of data being moved around, potentially allowing even high-resolution headsets to become untethered from the main computer system (it’s a real pain having cables connecting your headset to your computer).

I’m currently in the strange position of really enjoying my Oculus Rift and not being able to imagine anything better, while – at the same time – knowing that we are just at the beginning of this technology and that new developments will soon render my Oculus obsolete. I for one cannot wait to see what the next few years will bring. In the meantime, if you’ll excuse me, I have virtual worlds to explore – I’ll see you on the flip side. Until next time, have a good one!

Any comments or questions? – please feel free to send me an email at: **max@CliveMaxfield.com**

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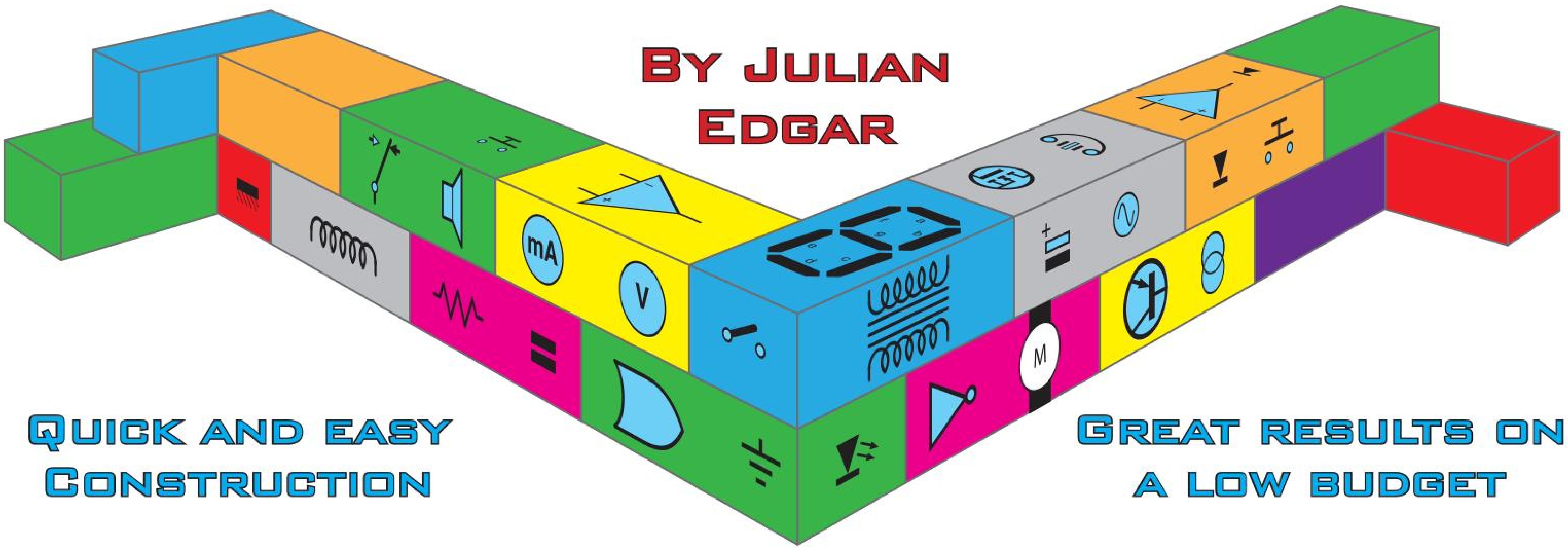

BY JULIAN EDGAR

QUICK AND EASY CONSTRUCTION

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GOOD QUALITY 2.1 AMPLIFIER MODULE

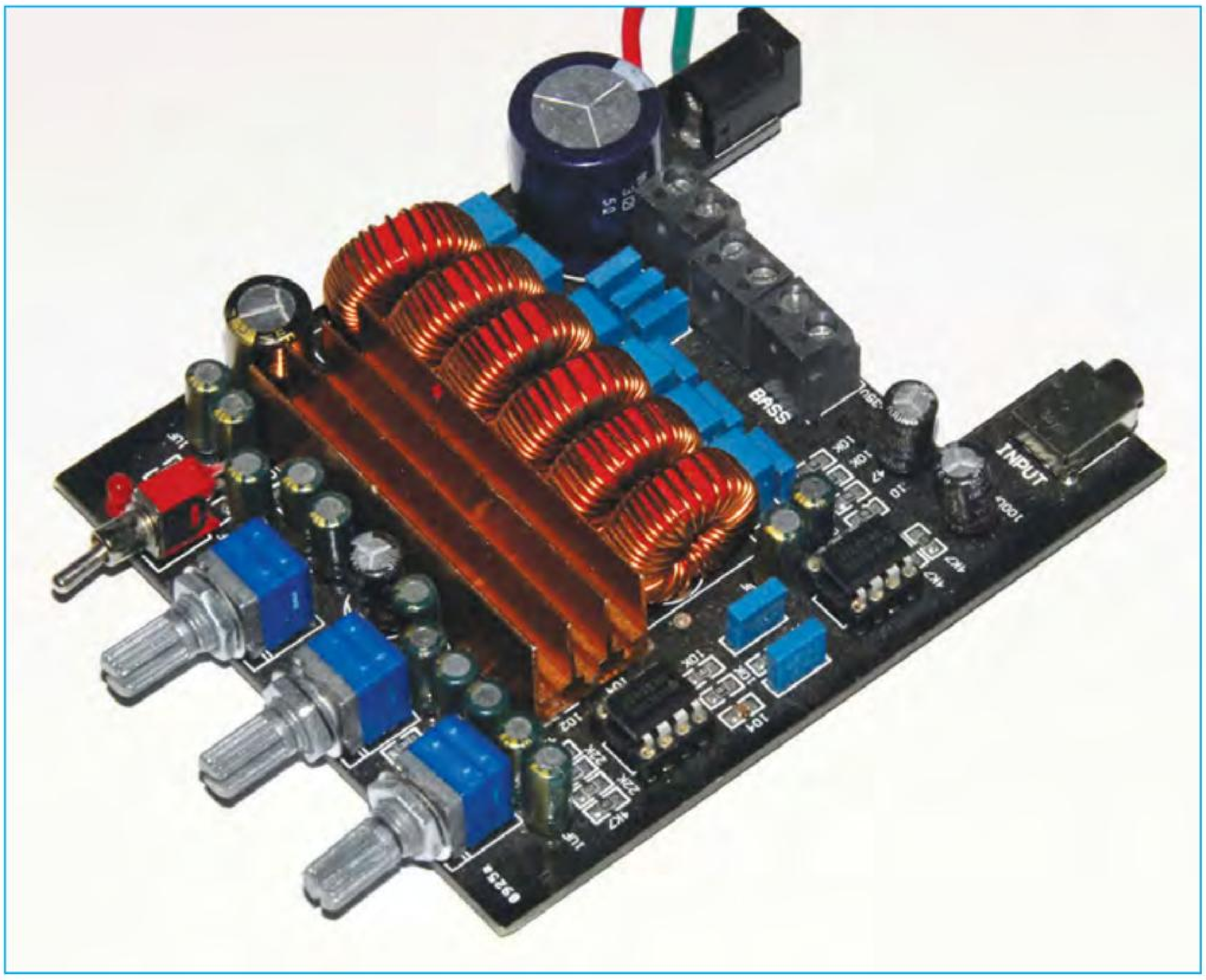
Large complex projects are fun, but they take time and can be expensive. Sometimes you just want a quick result at low cost. That's where this series of *Electronic Building Blocks* fits in. We use 'cheap as chips' components bought online to get you where you want to be... FAST! These projects range from around £15 to under a fiver... bargains!

Here's a really good 2.1 amplifier module that's at home in a lot of different situations. Do you want a test amplifier for checking speakers? This one will do it. Or maybe you want an amplifier to run a sound system in your child's room or home office? You won't find anything better for the money. Or do you want something more serious? Then team the amplifier module with a tone control module!

Class-D amp – derate for low THD+N

What we're talking about here is a class-D amplifier module based on two TPA3116 chips. It has two output channels, each nominally rated at 50W, and a third channel nominally rated at 100W. You can use it as a stereo amplifier, or as a 2.1 amplifier – that is, driving stereo speakers, plus the third channel driving a subwoofer.

In use, it's best to derate the module's maximum output power – at a full power of 50W per channel, the TPA3116 spec sheet shows that THD+N is a high 10 per cent! However, at half power of 25W per channel, THD+N is 100 times better at only 0.1 per cent.



This three-channel Amplifier Module *is superb value for money. It has rated outputs of 50W × 2 plus 100W × 1 with 10 per cent distortion – but at half power, distortion is only 0.1 per cent!*

Power and connections

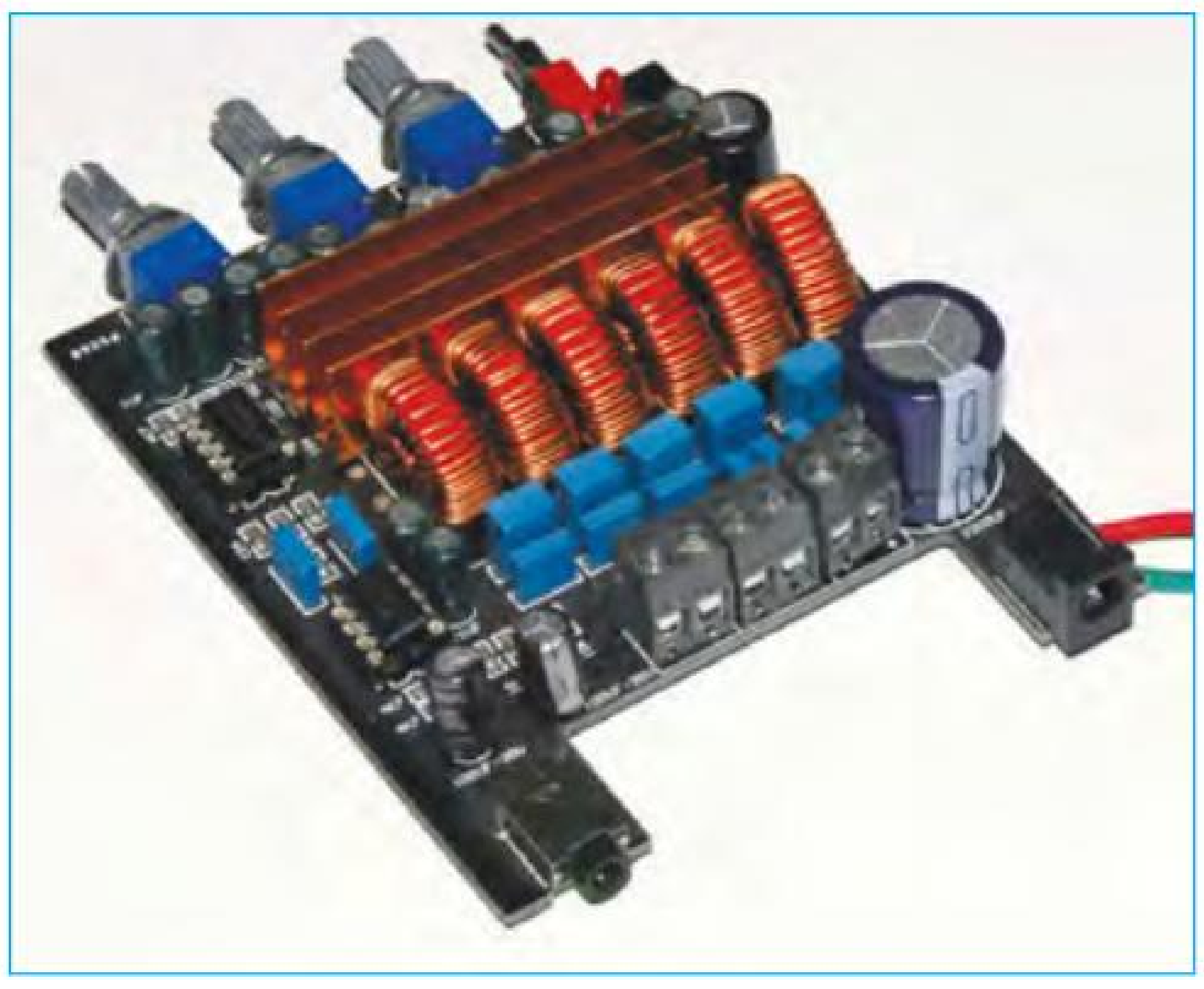
The module needs a 21V DC supply to provide full output power; but in general use it's happy with anything from 12V up to 25V. You can use any good plug-pack capable of suppling around 21V – a discarded (or new) laptop power supply is ideal.

The module has a 3.5mm stereo input socket, a DC power supply socket and a terminal block for the speakers. (Some versions have solder pads for the speaker connections.) An on/off switch and three potentiometers are mounted on the front edge of the board. These knobs are: stereo speaker volume control, subwoofer volume control and master volume control.

In use

I have been using this amplifier module now for about six months. It's outstanding – plenty of grunt, an excellent 102dB signal-to-noise ratio, able to drive 4Ω loads, and protected against over-current and over-temperature. And, talking about temperatures, the Class-D architecture means that the tiny heat-sink shown in the photos is more than adequate – on normal music material, even playing loudly, it barely gets warm.

So how do you use the module? One approach is to team it with second-hand speakers – for example, a discarded home theatre system comprising small satellite speakers and a subwoofer. Connect two satellite speakers to the stereo outputs, and the subwoofer to the third output.



The 3.5mm stereo plug input is at left and the DC power socket at right. The red and green wires are ones I soldered directly to the board to provide power without needing the right plug.

Using the two on-board pots, set the relative levels of the stereo pair and the subwoofer. Then, when these are set correctly, use just the main volume control to set the required listening level. (Or, if listening to MP3 files from a phone or similar, leave the main volume control at maximum and control the listening level with the volume control on the phone.)

The result is amazingly good – you'd think the amplifier cost £30, not around £10!

Another approach is to use the amplifier with just two higher quality speakers. Believe it or not, if you're not after audiophile quality sound, this tiny amplifier has performance that's good enough for the vast majority of listeners.

Adding tone control

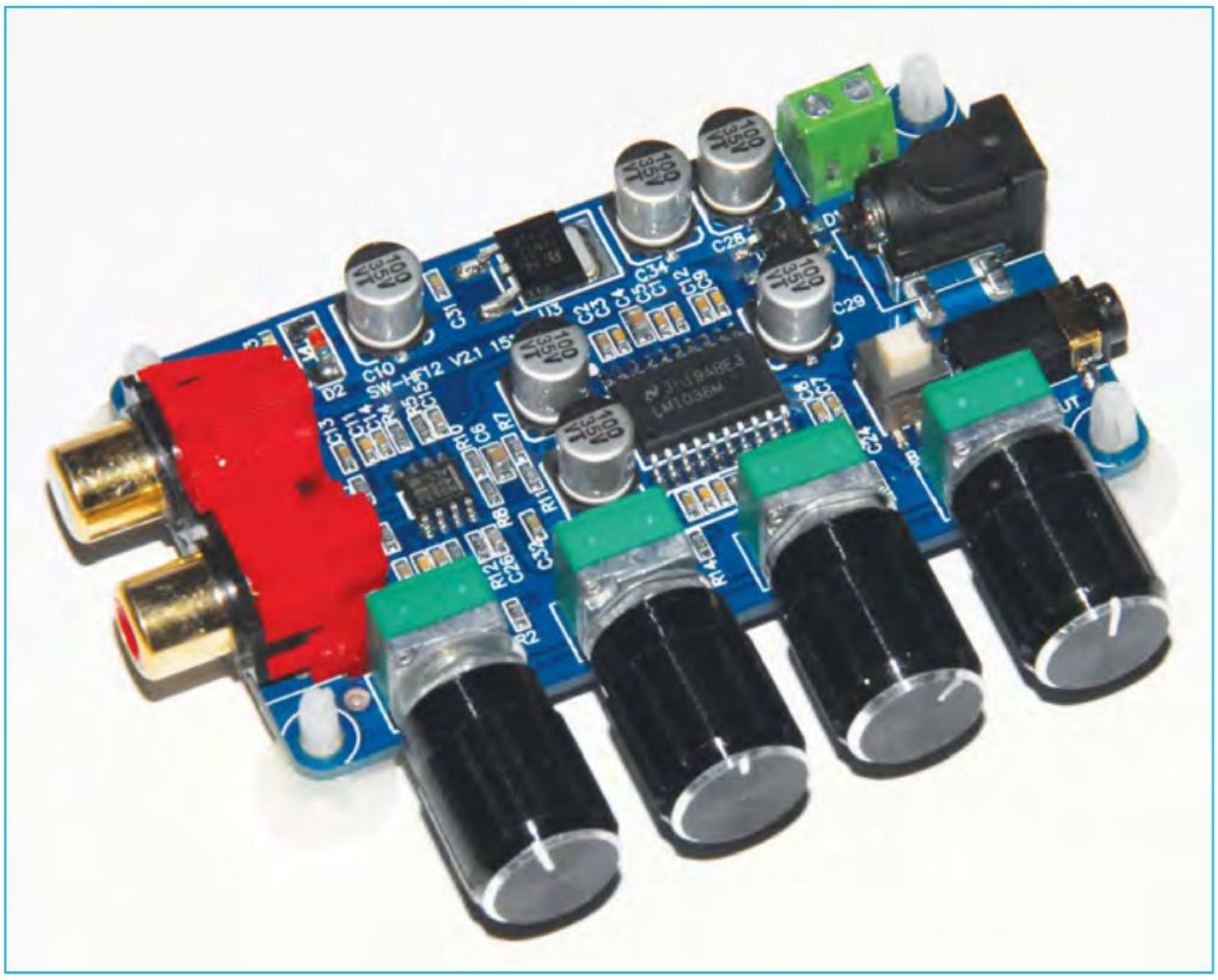
But what if you want a loudness button? Or separate bass and treble controls? In that case, welcome to the second of the modules I'm covering this month.

This additional module is a tone control board. It has volume, balance, bass and treble pots. Furthermore, on the board itself there is a loudness button. (This boosts bass and treble at lower listening levels.)

Power and connections

The output is via a 3.5mm stereo socket (so use a cable with 3.5mm stereo plugs at each end to connect to the amplifier module) and the input is via two RCA sockets. Power (12V) is supplied via either a DC-type socket or screw connectors (positive on the screw connectors is closest to the end of the board). To supply this power, you could add a 12V plugpack or use a small power supply operating off the amplifier power supply – only a few milliamps is required for the tone control board.

As its name suggests, this board is based on the LM1036 tone control IC. The IC has low distortion (typically about 0.06 per cent) but its signal-to-noise ratio at 80dB is not as good as the amplifier module. If the Chinese-built module has followed the data sheet for the IC, bass (a centre frequency of 40Hz) and treble (16kHz) are variable by ±15dB. The loudness button has a similar bass and treble boost – ie, up to 15dB at low levels. However, this boost drops away nicely as the volume control is advanced. This module has one unfortunate glitch – if the loudness button is operated when the music is playing, a pop can occur in the speakers.



If you want to add tone controls to the amplifier, this Preamplifier Module *will do the trick. It has bass, treble, balance and volume pots (knobs supplied!), and an on-board loudness button.*

The Preamplifier's *input is via a 3.5mm stereo socket, and power is supplied via either the screw terminals or the DC socket.*

Great value!

When I originally bought the amp module, I didn't dream that it would be of sufficient quality that I'd be using it during development of Hi-Fi loudspeaker systems – swapping only to a more expensive amp after my initial testing. Now the module has been retired from that function, and working with the tone control board, it is powering a stereo pair of speakers in my home office.

These two modules provide sound that literally only a few years ago would have cost you double or even triple their price.

Sourcing

To find the *Amplifier Module*, search eBay using the term, 'New 50W x2+100W TPA3116D2 2.1 HIFI Digital Subwoofer Amplifier Verst Board' or similar – at the time of writing, item 272050291976. It costs under £10, postage included.

To find the *Preamplifier Module*, search on eBay using the term 'LM1036 + NE5532 Stereo Preamp Preamplifier Treble/Bass Tone Board DIY Amplifier' or similar – at the time of writing, item 131573062034. It costs about £8, post included.

Next month

In January's issue we will look at an amazing 6A, 24V variable power supply with digital displays from as little as £20! So you definitely do not want to miss the next super *Electronic Building Block* article!

PCB SERVICE

CHECK US OUT ON THE WEB

Basic printed circuit boards for most recent *EPE* constructional projects are available from the *PCB Service*, see list. These are fabricated in glass fibre, and are drilled and roller tinned, but all holes are a standard size. They are not silk-screened, nor do they have solder resist. Double-sided boards are **NOT plated through hole** and will require 'vias' and some components soldering to both sides. **NOTE: PCBs from the July 2013 issue with eight digit codes** have silk screen overlays and, where applicable, are double-sided, plated through-hole, with solder masks, they are similar to the photos in the relevent project articles.

All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

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HAMMOND ELECTRONICS Ltd 33
JPG ELECTRONICS 72
LABCENTER . . . . . . Cover (iv)
LASER BUSINESS SYSTEMS 21
MICROCHIP . . . . . . Cover (iii), 10 & 57
PCB CART . . . . . . Cover (ii)
PEAK ELECTRONIC DESIGN 65
PICO TECHNOLOGY 35
POLABS D.O.O. 25
QUASAR ELECTRONICS 2/3
STEWART OF READING 56
TAG-CONNECT 35

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Next Month

Content may be subject to change

5-Element Yagi for DAB

What's your DAB reception like? Spasmodic? Subject to spitting and dropouts? You need a decent antenna rather than rely on the nearly useless extendable whip antenna fitted to most DAB radios. This 5-element Yagi antenna is specifically designed for DAB radio and should markedly improve your reception. In some cases it could mean actually receiving DAB signals where previously none were detected!

High Visibility 6-Digit LED GPS Clock – Part 1

Want a really bright 6-digit clock that you can see at a considerable distance? Would you like it to have GPS-time precision with automatic time zone and daylight saving adjustment? Well, have we got a clock for you! This new clock design uses six 56mm-high LED digits which are so bright that they seem larger than life.

High-performance stereo valve preamplifier – Part 1

This stand-alone stereo valve preamplifier is based on the *Currawong Amplifier* (November 2015-January 2016) but has a new power supply which runs off a low-voltage DC supply. It has very good performance, especially for a valve preamp, with low distortion and a very high signal-to-noise ratio of 105dB. It's easy to build too, with the preamp and power supply all on one PCB.

Teach-In 2016 – Part 12

In next month's *Teach-In 2016, Arduino World* will look at wireless networking and the ESPduino microcontroller. *Arduino Workshop* will introduce you to the extended I/O facilities offered by the Arduino Mega, and our programming feature, *Coding Quickstart* will show you how to get the best out of the ESP8266 wireless module. Last, but not least, our *Get Real* project will bring our current *Teach-In 2016* series to a conclusion by showing you how to get started with the Internet of Things (IoT).

PLUS!

All your favourite regular columns from *Audio Out* and *Circuit Surgery* to *Electronic Building Blocks, PIC n' Mix* and *Net Work.*

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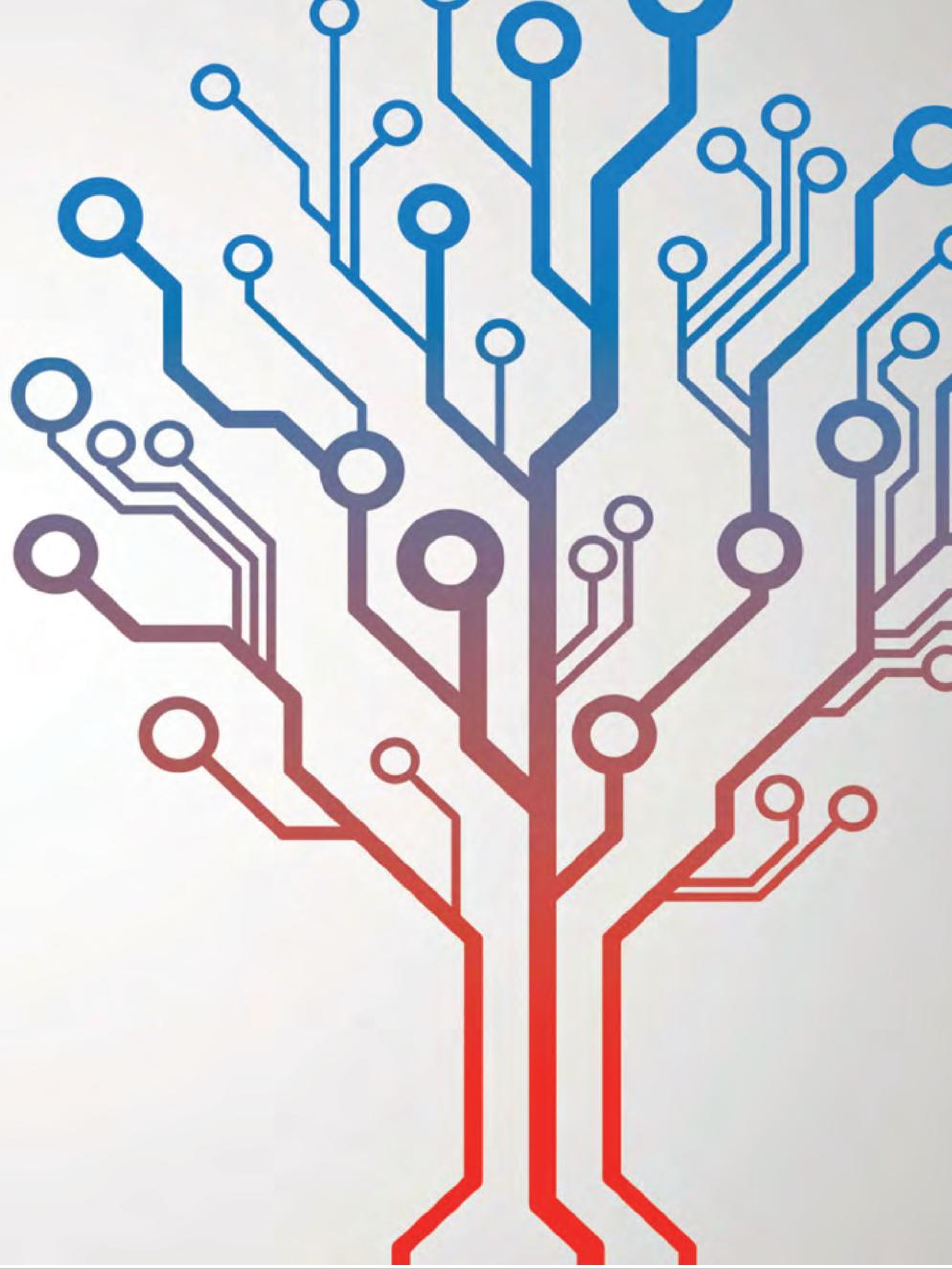

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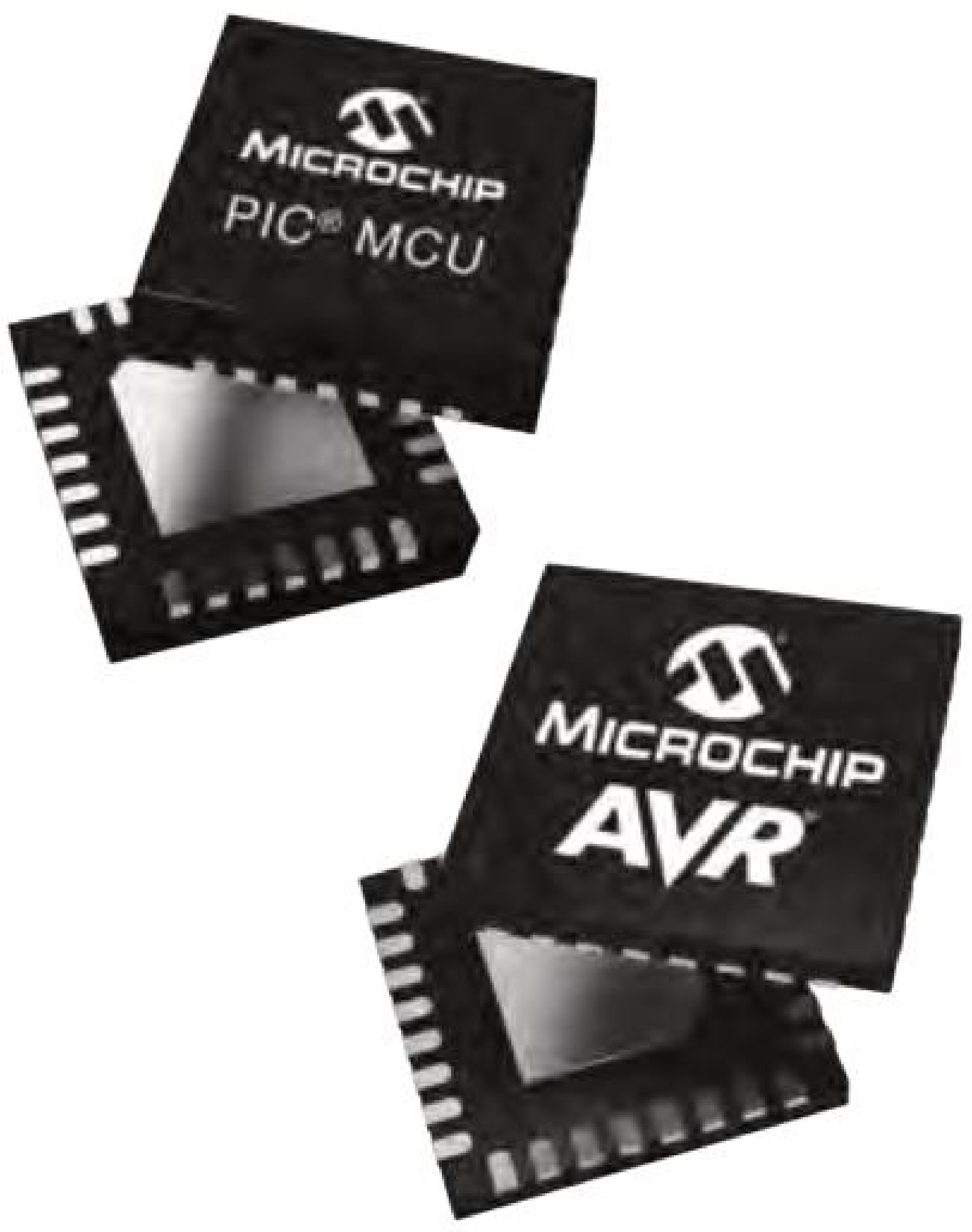

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